MINUTES OF PROCEEDINGS

OF

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OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CXLVIII.

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1901-1902.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

17 December, 1901.

CHARLES HAWKSLEY, President,
in the Chair.

(*Paper No. 3272.*)

"Motive Power from Blast-Furnace Gases."

By BRYAN DONKIN,[1] M. Inst. C.E.

THE utilization of blast-furnace gases to drive gas-engines for the production of power, although of quite recent date, has assumed considerable importance within the last few years. Such progress has been made, and so many practical difficulties have been overcome, that mining and mechanical engineers are beginning to appreciate the valuable and reliable source of power now at their disposal. It may fairly be assumed that the economical and practical use of gases from blast-furnaces in gas-engine cylinders will greatly influence the future of the iron industry. The total annual output of iron from blast-furnaces all over the world in 1899 was over 40,000,000 tons. This represents a possible source of power which can no longer be ignored; and some account therefore of the origin and progress of the attempts hitherto made to utilize it may be not without interest.

Blast-furnaces form most efficient generators of power-gas. The fact that they constitute excellent gas-producers was noticed by Mr. F. W. Lürmann as early as 1870,[2] by Mr. Lencauchez in 1878, and by others. The gases given off during the process of smelting iron ore have for many years been utilized to a certain extent. Fifty years ago they were considered to be of little value, and were simply burned as they issued from

[1] The lamented death of the Author, which occurred on the 4th March, 1902, accounts for the absence of a reply to the Correspondence on this Paper. —SEC. INST. C.E.

[2] *Dingler's Polytechnisches Journal*, vol. cxcv. p. 254.

the top of the furnace. The next step, about the middle of the past century, was to make use of a portion of the gases for heating the air-blast, and to raise steam for driving large air-blowing engines. This application was the only one available at the time, when internal-combustion engines were undeveloped, and the hot gases could be treated only as fuel. For many years these valuable gases were, and they still are, thus utilized; and in some cases arrangements existed for conveying them to considerable distances, when used for raising steam; but no attempt was made to employ them economically, because a portion only of the large quantity produced could be turned to account. The idea of making more extended use of them in gas-engine cylinders was put into practice in Belgium, Germany, and Great Britain, in 1895 (see Table, p. 26).

Composition of Blast-Furnace Gases.

The iron ore fed into a furnace contains much oxygen, which, combining with the carbon in the fuel, is given off in the gases. The earthy particles in the ore are dissolved by the fluxes, chiefly limestone, and melted at the very high temperature of the furnace; the flux is decomposed, and the two combine to form slag. But to maintain the requisite temperature, much more oxygen is needed than is present in the iron ore. This is furnished by the hot air-blast, the oxygen of which combines with the carbon in the fuel to form carbonic acid (CO_2); the carbonic acid is subsequently reduced to carbon monoxide (CO) by taking up more carbon; and finally the monoxide is again partially oxidized to carbonic acid by taking up oxygen from the iron in the ore. Hydrogen, another constituent of producer-gas, is also contained in the coke, and in the moisture of the air; but, as the analysis of blast-furnace gases shows, it is present in small quantities only. The gases given off contain a large percentage of nitrogen, a certain quantity of carbon monoxide and carbonic acid, a little hydrogen, and a small percentage of hydrocarbons and of water-vapour. Carbonic acid has no calorific value, being an inert gas, while carbon monoxide has a calorific value of 342·3 British thermal units (B.Th.U.) per cubic foot.

The relative quantities of carbonic acid and carbon monoxide in the gases vary, and the process of combustion is always complex. Hitherto the efficiency of the furnace has been determined chiefly by the proportion of CO_2 contained in the gases; and it is upon the ratio by weight of CO_2 to CO, called the "coefficient of reduction,"

that the calorific value of the gas depends. The calorific value of the mixture of gases from a blast-furnace is continually changing, hour by hour. The larger the proportion of CO_2, the greater will be the quantity of gas yielded at the furnace-mouth, but the lower will be its calorific value. If it contains much CO_2, less heat will be carried off, and more will be utilized in the furnace for smelting the ore, for liquefying the impure and earthy particles, and for amalgamating them with the fluxes to form slag. Less carbon being required, an economy in the coke fed into the furnace will be obtained, and this appears to have been hitherto the standard at which the iron-master has aimed.

From the engineer's point of view, such a gas would be too poor to ignite in a motor-cylinder; and it is the relative amount of CO which, on account of the calorific value of that gas, determines whether the mixed gases are practically valuable or not. For instance, in a particular blast-furnace yielding 163,620 cubic feet of gas per ton of pig-iron, the volume of CO_2 was 58 per cent. of the volume of CO, and the calorific value of the gas was 101 B.Th.U. per cubic foot. In other furnaces, with 70 per cent. of CO_2, the value was about 110 B.Th.U., and with 50 per cent. 122 B.Th.U., per cubic foot. In whatever way the processes of combustion are carried out, there is always enough CO in the gases given off to render the mixture combustible. Professor E. Meyer says, "The smaller the consumption of coke in a furnace, the better will be the efficiency of the furnace as a whole, but the less will be the work done by the gases when utilized in a gas-engine."[1]

The following Table gives the composition of the gases from several blast-furnaces:—

CHEMICAL COMPOSITION OF BLAST-FURNACE GASES AT VARIOUS IRONWORKS.

Name of Ironworks.	Composition by Volume, Per Cent.					
	CO.	H.	CH_4.	CO_2.	N.	H_2O
Wishaw, Scotland	24·75	2·3	0·75	5·75	66·4	..
Frodingham, England	27·3	1·5	..	6·0	65·2	..
Friedenshütte (Germany)	30·0	3·0	..	6·5	60·5	..
Donnersmarck (Germany)	31·0	3·4	..	7·8	57·8	..
Hörde (Germany)	32·0	2·5	..	8·5	57·0	..
Seraing, Belgium	28·1	1·39 (H. and CH_4.)		8·9	50·5	11·0

[1] Zeitschrift des Vereines deutscher Ingenieure, vol. xxxiii. pp. 448, 483.

Utilization of Blast-Furnace Gases.

In the endeavour to turn these gases to good account, engineers were confronted by two problems. First, whether blast-furnace gases were really valuable, and would burn satisfactorily; secondly, whether, in the existing state of the knowledge of the subject, a gas-engine was the most suitable kind of motor for converting into power the heat they contained. According to Mr. F. W. Lürmann, an eminent German authority on the subject, when the gases are burned under boilers, about 10 per cent. is lost by leakage from the pipes and during smelting, about 28 per cent. is used to heat the air-blast, about 40 per cent. is utilized under the boilers, and the balance of 22 per cent. is wasted. Assuming that 162,000 cubic feet of gas are produced per ton of pig-iron per 24 hours, the disposal of that quantity may be apportioned roughly as follows:—leakage, 16,000 cubic feet; heating the air-blast, 45,000 cubic feet; burning under boilers, 64,000 cubic feet; not utilized, 37,000 cubic feet. Thus, even with the present method, in which no attempt is made to use them economically, 37,000 cubic feet of gases per ton of iron per day, now wasted, would yield about $\frac{37,000}{123 \times 24} = 12\frac{1}{2}$ HP.; but if gas-engines only are used, 28 HP. per ton of iron per day may be obtained after deducting 6 HP. for compressing the air. At Seraing, in Belgium, where the ironworks are on a large scale, the average daily output is 600 tons of pig-iron. Thus the power which might be utilized would be about 17,000 HP. Mr. H. Hubert, of Liége, estimates the average power available for industrial purposes at 23 HP. per ton of iron per day. He sums up the question of economy thus:—If after heating the air-blast the remainder of the gases are burnt under a boiler, they will produce 12·5 HP. per ton of pig-iron per day. If used in a gas-engine, they will yield 32 HP. per ton of iron per day.

Further, the low thermal efficiency of these gases when burned under boilers has to be considered. Analysis shows that they contain about one-third part of combustible gases, chiefly CO with a little hydrogen, the remainder being mostly inert nitrogen and CO_2. The value of furnace-gas under boilers is principally due to the CO which it contains. It is when steam-engines with boilers come into direct competition with gas-engines, and the same gases are available for both, that the advantages of utilizing these gases in the cylinders of gas-motors become apparent. With an average

steam-engine, about 400 cubic feet of gas are required under a boiler to produce 1 HP.-hour, or at least four times as much as when the gas is used in a gas-motor. But still greater economy could be effected if the present system of steam-engines, with large ranges of boilers and their chimneys, were discarded, and the gases worked the air-blast cylinder by means of a gas-engine, as is now done in many cases. Under these new conditions, and with greater care in preventing waste, a vast store of power is practically obtainable.

Mr. Lürmann calculates the production of power in Germany at 570,000 HP. for an annual output of 7,400,000 tons of pig-iron, or 20,000 tons per day. If in a blast-furnace treating about 100 tons of iron ore per 24 hours the gases given off were all utilized in a gas-engine cylinder, there would be a surplus of about 2,000 HP. after providing the blast and heating the air for the furnaces. For producer-gas 1 lb. of fuel per horse-power-hour is the usual average allowance. Mr. W. H. Booth states that, calculating the consumption of a blast-furnace at 2 lbs. of fuel per horse-power-hour, 1 lb. may be taken as required for the furnace, and 1 lb. is left for power purposes. This is probably a minimum, as other authorities give a higher figure. Assuming, says Mr. Booth, that 10 million to 12 million tons of fuel are burned annually in English and Scotch furnaces, 2½ million HP. would be produced if the gases could be properly utilized.

As regards the utilization of the gases in the form of an explosive charge, the large proportion of nitrogen they contain presents no difficulty. Before a gas can be burned in an engine-cylinder it must be mixed with a certain quantity of air, varying according to the thermal value of the gas. With these blast-furnace gases, therefore, the ratio of air to gas must be diminished or increased to form the charge. The most satisfactory mixture for lighting-gas has been found to be about 1 cubic foot of gas to 8 cubic feet of air. With producer-gas, about 1 cubic foot of gas is required to 1·3 or 1·4 cubic foot of air; while 1 cubic foot of blast-furnace gases requires for its dilution an equal volume of air. In one of Professor Meyer's trials, an engine exerting 120 HP. when driven with lighting-gas developed 100 HP. when worked with blast-furnace gas, or 18 per cent. less power. Taking two engines with cylinders of equal volume, say 8, let 1 volume of lighting-gas and 7 volumes of air be admitted to the one, and 4 volumes of blast-furnace gases and 4 volumes of air to the other. Assuming the calorific value of the lighting-gas to be 584 B.Th.U. per cubic

foot, and that of the blast-furnace gases 100 B.Th.U. per cubic foot, the power will work out in the following ratio:—

$$(1 \times 584) \div (4 \times 100) = \frac{584}{400}.$$

It is owing to this small dilution with air, and to the high compression used, that the thermal efficiency of blast-furnace gases in an engine-cylinder is so high, as much as from 20 per cent. to 26 per cent. calculated on the brake horse-power having been obtained. After allowing for all the power required for heating the blast and for generating steam for driving the blowing-engines, Mr. J. Riley,[1] in 1898, estimated the horse-power available, per ton of pig-iron per day,[2] at 6·73 HP. in two English furnaces turning out 800 tons of pig-iron each per week. According to the best authorities about 40 per cent. of the total power appears to remain over, after utilizing the gases for the purposes of the furnace.

Disadvantages of Blast-Furnace Gases.

As regards the anticipated disadvantages of this new source of motive power, some have been already overcome, or found hardly to exist. The idea that blast-furnace gases could be satisfactorily burned in an engine-cylinder was at first treated as visionary. Mr. Lürmann doubted the possibility, on account of the dust they contain, their high temperature, fluctuations in composition and pressure, and low calorific value;[3] but he has since greatly modified his views. The objection urged against their use by many iron-masters, when the subject was first discussed and experiments were started, was their low calorific value. The same points were brought out in a Paper by Mr. Enrique Disdier, of the Bilbao Ironworks.[4]

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[1] Journal of the Iron and Steel Institute, 1898, vol. liii. p. 36.

[2] Apparently this should be "per ton of pig-iron per *week*," *i.e.*, taking the rate of production of pig-iron adopted by the Author (viz., 1 ton of pig-iron produced per day of 24 hours), 6·73 I.HP. × 7 = 47·1 I.HP.

Mr. Riley assumes that 181,670 cubic feet of gas are produced per ton of pig-iron made, of which about 89,580 cubic feet are available under the conditions mentioned, and that 79·12 cubic feet of gas yield 1 I.HP.-hour, and $\frac{89,580}{79 \cdot 12 \times 24} = 47 \cdot 1$ I HP. per ton of pig-iron produced per day.—Sec. Inst. C.E.

[3] *Stahl und Eisen*, 1898, part 1, p. 250.

[4] Journal of the Iron and Steel Institute, 1899, vol. lv. p. 130. In a valuable Paper by Mr. Greiner, mentioned later (p. 12), a Table is given showing the connection between the quality of the ore treated and the dust in the gases, from which the following figures are taken. At the Roechling works at

Most of these difficulties are now practically obviated, and only one, the dust contained in the gases, has to be provided for. As regards fluctuations in composition and pressure, the quantity generated is so large that, by allowing the gases to pass to a gas-holder and thence to the engine, their quality and pressure are maintained fairly uniform; but even this is not always found necessary. Ironworks are usually on so large a scale that several furnaces are often worked simultaneously. If one furnace be yielding gases of poorer quality, their deficiency in calorific value will be made good by mixing them with the gases from others. Nor are the variations of pressure so great as has been supposed. Professor A. Witz tested the gases at Differdingen, Luxemburg, by placing an anemometer, a pressure-gauge and a thermometer in the pipe conveying them to the boilers. He found that the speed of the gases varied between 9·2 feet and 29·5 feet per minute, and their temperature between 140° and 194° F.; while during a test lasting 6 hours the total fluctuations in pressure were only equal to 1·5 inch head of water. In order to cool the gases, they are often passed through large vertical pipes into which cold water is injected in spray.

The lowness of their calorific value, containing as they do only between 27 per cent. and 30 per cent. of combustible gases, has not, as was anticipated, proved a drawback to their use. They are usually ignited electrically in a gas-engine, and no difficulty is experienced in thus firing the charge. The varying calorific value of blast-furnace gases has been the subject of careful experiments by Professor Witz with his bomb calorimeter. The gases were tested at constant volume (higher calorific value);[1] the results were thus slightly in excess of

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Völklingen, oolitic ores from Luxemburg are used in the furnaces, basic iron is made, and the quantity of dust contained in the gases on leaving the furnace is 13½ grams per cubic metre. At Oberhausen basic iron is made from Swedish hæmatite ore, and the gases contain 5·3 grams; while at the Seraing works, Spanish and purple ores are treated, Bessemer iron is produced, and the gases contain only 3 grams of dust per cubic metre, as they leave the furnace.

[1] In the higher calorific value, used in France and Belgium, the water formed by combustion in a calorimeter is taken as condensed, and the heat it contains is reckoned as part of the calorimetric value of the gas. In the lower calorific value, as calculated in Germany, England and elsewhere, the latent heat of the water is deducted from the calorific value, determined in a calorimeter. The difference between the two values is not so marked, nor of such importance, in blast-furnace gases as in lighting-gas, because the former contains much less hydrogen and practically no hydrocarbons. For further details, see Meyer, Zeitschrift des Vereines deutscher Ingenieure, vol. xxxiii. pp. 448 and 483; and Hubert, "Utilisation directe des Gaz de Hauts-Fourneaux," Bulletin de la Société de l'Industrie Minérale, 3rd series, vol. xiv. p. 1461.

those obtained by the German or English method, in which the lower calorific value at constant pressure is taken. Seventy-nine determinations were made. From twenty-seven on Belgian furnace-gases an average calorific value of 111 B.Th.U. per cubic foot was obtained; nineteen samples from Luxemburg gave an average of 114 B.Th.U. per cubic foot; twenty-three samples from German blast-furnace gases an average of 108 B.Th.U.; a single English sample 110 B.Th.U.; and nine samples from Southern France and Spain an average of 107 B.Th.U. per cubic foot. From these tests Professor Witz estimates the average calorific value of blast-furnace gases at 110 B.Th.U. per cubic foot. If the flux is acid, it may fall to 95 B.Th.U. per cubic foot. The gas is of course comparatively poor, and combustion is difficult unless compression in the gas-engine cylinder is carried to between 7 and 9 atmospheres. In tests made by Mr. Köhler in 1898, at Duisburg, the calorific value (higher) of gases from the same furnace, throughout trials on two different days, was successively 106·4, 108·4, 112·3 and 110·4 B.Th.U. per cubic foot.

As is well known, the secret of economy in a modern gas-engine is the high compression of the gaseous charge previous to ignition. With lighting-gas, if compression be carried too far, there is a danger of premature ignition. The lower the calorific value of the gas, the higher the compression it will bear without risk of explosion. Consequently to utilize blast-furnace gases, which contain so small a proportion of combustible gases that they are almost at the lowest limit at which such a mixture will ignite, it is necessary to adjust the size of the compression-space at the end of the cylinder, diminishing it as the calorific value of the gas used decreases. As the quality of the gases varies with the fuel burned, the kind of iron made, fluxes employed, etc., the engine should be adapted to the gases, and to the working-conditions of the furnaces. The very high compressions required present no difficulties to the engineer, and however poor the gas may be, if it is sufficiently compressed, ignition may be secured with practical certainty. Compressions to between 7 and 9 atmospheres, measured on the indicator-diagram, are very usual. At Seraing, in 1898, the gases were compressed to 7½ atmospheres, at Differdingen to 8 atmospheres; and in the latest trials at Seraing compression was increased to 11 atmospheres.

The low calorific value of these gases may even be turned to advantage, because, by reason of the high compression they will bear without igniting, an exceptionally high thermal efficiency is obtained. In other words, the ratio of the heat turned into useful

work to that supplied to the engine in the gases is as high as in the best engines driven with lighting-gas, and sometimes higher.

The last and hitherto the greatest objection to the use of these gases is the quantity of dust with which they are charged. This dust is chiefly metallic dust with some lime, but depends much on the kind of ore used, and other working-conditions. Some writers at first maintained that it would clog the valves and would attack parts of the engine, causing them to deteriorate rapidly. The opinion now generally held is that the speed and the high degree of compression of the charge cause nearly all the dust that remains after cooling the gases to be blown out of the cylinders with the exhaust. At the discharge-valve fine white dust is often deposited, and has been collected by the Author. The dust with which the gases from the furnace is charged is of two kinds, both of which are carried forward with the current of gas from the furnace. The heavy metallic particles can be arrested at the bottom of the large gas-pipes; the light impalpable dust is chiefly removed by washing. The quantity seems to be about 2 to 3 grams per cubic metre (about 1 to 1½ grain per cubic foot) of gas, but it varies considerably in different places. Professor Witz estimates it at 12·5 grams per cubic metre (5·5 grains per cubic foot) when the gases leave the furnace. Of this, 10·0 grams is precipitated in the pipes, 2·3 grams is retained in the purifiers, and the remainder (0·2 gram) is mostly blown out with the exhaust gases.

The amount of cleaning required varies in each case with the quality of the fuel and ore used. As the manager of the Gas-motoren-Fabrik Deutz has pointed out, it is incorrect to speak of blast-furnace gases as being sent to the engines in their original condition, because in nearly all works the gases, before passing to a Cowper air-heating apparatus or being used under the boilers, deposit part of their dust in the long pipes of large diameter through which they are drawn from the mouth of the furnace. Thus the question is one of degree only. Even before it was proposed to utilize the gases in engine-cylinders, the importance of purifying them from dust before they reached the boilers was recognized, but it was not done. At the Micheville Ironworks in France the gases, although hitherto used only to generate steam, descend through six large vertical pipes 62 feet high and 8 feet in diameter, and ascend through others 13 feet in diameter. The bottom of each pipe rests in a cone filled with water, upon the surface of which the gas strikes in its passage from one pipe to another. In another French furnace the gases, as they are led through the pipes, have to pass upward

through a grating covered with a layer of iron turnings, and here they are said to deposit a considerable portion of the solid impurities they contain. In many German works there are large purifiers occupying much space. Sometimes the gases are washed with water, sometimes they are treated by the dry process. To the former class belongs the Theisen centrifugal washer, for freeing gases from dust—of a type which has some practical application in Germany. It is made in several sizes, depending on the quantity of gas to be treated, and is driven by a belt from a separate motor. The water is dashed about and the gas is cleansed by being brought into close contact with it; and if lighted on leaving the washer it burns with a blue flame. The cooling-water flows in a contrary direction to that of the hot gas, and the quantity is carefully regulated. On entering the washer the gases contain on an average 3·342 grams per cubic metre (1·46 grain per cubic foot), and on leaving only 0·010 gram. Their temperature, which is often 110° C. on entering, is also considerably reduced at their exit. It depends on the quantity of water supplied and the temperature at admission, but it is generally a few degrees higher than that of the water passing out. The washer also acts like a pump, drawing the gases from the main at a vacuum of about 1½ inch of water, and forcing them forward at a water-pressure of 3½ inches. It deals with the lighter dust in the gases, which is not deposited in the gas-mains; of the heavier or metallic portion nearly all is eliminated beforehand. The washer treats the gases by the wet process, apart from other apparatus dealing with them by the dry method. The latter system requires a very large plant and occupies much space.

Besides these purifiers it was at first supposed that numerous auxiliary washers and scrubbers were necessary, but this is now found not to be the case. Even the brief experience gained within the last two or three years shows that the difficulty of getting rid of the various kinds of dust is practically solved in different ways. In some works which the Author has visited the use of scrubbers is preferred, but they are not considered absolutely necessary. According to Professor Witz, simple means suffice, so long as the gases are thoroughly cooled; but the question is best answered by reviewing briefly the methods already employed in German and Belgian ironworks, where large gas-engines are worked with these gases.

At Seraing, where at first the engineers had no previous experience to guide them, the gases for feeding the 200-HP.

engine, after being cleaned on leaving the furnace in the manner usual with gas to be burnt under the boilers, were passed through coke scrubbers with water injections. There were three pairs of these scrubbers, each 5 feet in diameter and 19 feet 8 inches high. In spite of these precautions the dust collected rapidly in the engine. It was then determined to re-model the interior of the cylinder and the arrangement of the valves and cooling-water; and this was so successfully carried out that it was found possible to dispense with the scrubbers altogether, and to draw the gas directly from the pipe conveying it to the boilers. In fact, the same pipe serves both boilers and gas-engines. The gases pass through the usual long vertical gas-pipes contained in a large wrought-iron cooler placed in the open air. Here water is sprayed on to them from the top and collected in troughs at the bottom, and thus answers the double purpose of cooling and cleansing. The main object is to cool the gases, in order to reduce them in volume and thus admit a larger quantity into the cylinder at each stroke. Care is taken to regulate the amount of water; if too much is used the gases lose in calorific value. They are perhaps rather less clean than elsewhere, and contain about 10 grams of heavy dust, and about 2 grams of light dust, per cubic metre (4·4 grains and 0·9 grain, respectively, per cubic foot); much of the latter passes out with the exhaust. During the trial witnessed by the Author in March, 1900, he collected some of this dust and found it soft, not gritty to the touch like sand, but more like flour.

Great trouble was experienced in dealing with the gases at the Friedenshütte works in Upper Silesia, where they are charged with much heavy zinc-dust. After two years of tentative efforts and repeated modifications of the purifying-apparatus, the Deutz firm succeeded in overcoming the difficulties. The gases are now cleansed by passing them through scrubbers and sawdust purifiers, and by the time they reach the engine they contain practically no dust. At the Donnersmarck Ironworks, to which a gas-plant has been supplied by Messrs. Körting Brothers, of Hanover, the gases are cleaned in scrubbers and sawdust purifiers, water injections being sprayed upon them from above. As it was found that the dust clogged the coke with which the scrubbers were filled, and obstructed the passage of the gases, the coke was removed. The gases are now simply passed up the pipe, and the water playing upon them from above is said to clean them effectually. At Hörde the gases are passed through five dry purifiers, a scrubber, and a sawdust cleaner, and are made to travel over a distance of 1,500 feet, after which they are practically free from dust. Where much

purification is required, this is the usual method, the system of cleaning with coke and sawdust, as is done with power-gas, being found sufficient. At Differdingen there are water-collectors in the pipes conveying the gases to the engine; the gases are also filtered through a sieve as they reach the cylinder and here a good deal of dust is deposited. The engine worked for 3 months with these gases, without taking out the piston for the purpose of cleaning the cylinder, etc.

In May, 1901, Mr. Greiner read a Paper[1] before the Iron and Steel Institute on the question of dust in blast-furnace gases. At Differdingen difficulties occurred with the gas-engine, and the gases contained an excessive quantity of dust, viz., 4 to 5 grams per cubic metre (1·75 to 2·2 grains per cubic foot), while at Seraing the amount was only ¼ to ½ gram per cubic metre (0·1 to 0·2 grain per cubic foot). In order to reduce the quantity to about ¼ gram per cubic metre, the following method has been employed with good results. All gases pass successively through two large fans 4 feet 11 inches in diameter, and driven at 900 revolutions per minute, and water enters in the centre of the fans with the gases. Such an apparatus is found sufficient to clean them and to supply gas to the six 600-HP. gas-engines, and no difficulty is now experienced.[2]

The cylinder of a gas-engine should be carefully constructed internally, without sharp angles or corners where dust can be deposited, and the interior should be smooth, so that any dust reaching it may be driven out with the exhaust. The number of dust-catchers depends upon the ores and fluxes used in the furnaces, the fuel burnt, and the air-pressure. The best proof of the non-deleterious effect of the dust lies in the fact that some large motors have been working successfully for two and even three years without experiencing trouble from deposit or clogging. Time and more experience alone will show whether engines driven with thoroughly purified gases do more work and wear better than those in which only partly cleaned gas is used.

Large Gas-Engines.

There were two difficulties to be overcome before gas-engines driven with blast-furnace gases could be successfully utilized to their full extent. The first, now practically surmounted, is to

[1] Journal of the Iron and Steel Institute, 1901, vol. lix. p. 56.

[2] See also Addendum at p. 26.

construct gas-engines large enough for this class of work. When it was found that blast-furnace gases would ignite satisfactorily in an engine-cylinder, a great impetus was given to the manufacture of large gas-engines, and the production of motors and plants in sizes not thought possible 5 years ago was stimulated. At that time gas-engines were made chiefly up to from 100 HP. to 250 HP., but new and larger kinds have now been brought out by several of the leading gas-engine makers in Europe and America. Engines up to 1,000 HP. and 1,500 HP. are being designed and made, and some are now running; and a two-cycle engine, the Oechelhaüser, has hitherto been worked with these gases only. When the vast volume of gases generated hourly is considered, the need for large gas-engines to turn them to the best account will be evident.

To start these large engines easily without load is an important operation demanding some care, but it is usually effected without difficulty. At Seraing a winch worked by hand is employed, gearing into the fly-wheel. The cylinder is first filled with a mixture of air and benzine vapour, the charge thus formed is compressed, and when at a sufficiently high pressure, an electric spark is passed into it, an explosion ensues, and the engine is started. At other works compressed air is used.

The other important question, as to the best way of driving the air-blowing cylinders from high-speed gas-engines, has been solved. As the first gas-engines working with these gases drove dynamos by belts, their comparatively high speed was an advantage. But it was soon seen that, to realize the highest economy, it was desirable to apply them directly to drive the air-blowing cylinders which are necessary in blast-furnace work. Makers have adopted different methods of adjusting the speed of the engine to that of the blower, and many gas-engines coupled direct to blowers are now at work. Steam-engines can be driven more slowly than is convenient for gas-motors. In the Author's opinion the air-blowing cylinders may often be driven direct by a crank or cranks on the same shaft as the gas-engine. The latter, it must be remembered, cannot be forced, and should be worked if possible at maximum load, to obtain the maximum economy. On the other hand, with so large a quantity of gas available, maximum economy is not a point of so much importance as simplicity, regularity, and freedom from accident. Lang-Hörbiger or small Corliss valves, which allow the speed of the blower to be increased up to 120 revolutions per minute, are now much used. At Seraing, where the "Simplex" engine runs at about 100 revolutions per minute, it is coupled direct

to the blowing-cylinder, the piston-rod of the engine being carried through the cylinder-head to the piston of the blower. The latter delivers 1,640 cubic feet of air per minute at a pressure of 15 inches of mercury. By a special arrangement the pressure and the discharge of air can be varied, the pressure increasing as the speed of revolution of the gas-engine diminishes. Thus the blower, which is fitted with Lang-Hörbiger valves, responds to all the varying exigencies of the furnace.

History of the Utilization of Blast-Furnace Gases in Gas-Engines.

In the endeavour to turn this great source of power to useful account, only three kinds of large gas-engines have been worked up to the present time:—the Otto, the "Simplex" and the Oechelhaüser.[1] Of the Otto four-cycle engine, used both in Germany and England it is unnecessary to say much; the "Simplex" and the Oechelhaüser engines will be described later. Unfortunately the development of gas-engines driven with blast-furnace gases has not proceeded nearly so rapidly in England as abroad. In Germany and Belgium each iron-master and engineer deals with the gases in the way best suited to the furnaces from which they are drawn, and their purification is generally carried out as already described.

To Mr. B. H. Thwaite, Assoc. M. Inst. C.E., is due the merit of having been the first, after careful study, to apply these gases to produce power in a gas-engine, but the Belgian and German experimenters worked independently. In May, 1894, he proposed to draw off the gases from the tops of blast-furnaces and to pass them, after purification, into the cylinder of a gas-engine. The gases were first conveyed through a large gas-main to the condenser, where the tar and ammonia were recovered. Part was then utilized in the old way to raise steam in boilers and to heat the air-blast, and part was forced to a scrubber and purifier, and thence to the holder and the gas-engine. At the Glasgow Iron and Steel Works, at Wishaw in Scotland, Mr. Thwaite worked an "Acme" engine with these gases in February, 1895. The engine was of the ordinary Otto four-cycle type, and drove a dynamo for supplying electric light to the works. The diameter of the cylinder was 12 inches, the stroke 20 inches, and the revolutions 190 per minute; and when worked with blast-

[1] A 350-HP. double-acting two-cycle Körting engine has now been made, but is not yet at work. See *The Engineer*, vol. xci. p. 23, for details and illustrations.

furnace gases it developed about 15 HP. It was tested by Mr. Booth in August, 1896, when some difficulty was found in starting; but the results obtained were good. The calorific value of the gas used was 126 B.Th.U. per cubic foot, and it contained 27·8 per cent. of combustible gases. The furnace yielded between 170,000 cubic feet and 180,000 cubic feet of gas per ton of iron smelted. The consumption of the engine was about 84 cubic feet of gas per indicated horse-power-hour. Taking the fuel used as a basis of calculation, the consumption was 1·6 lb. per electrical horse-power-hour, and 1·1 lb. per indicated horse-power-hour. Thus, for every 1½ lb. of coal burnt in the furnace, not only was the iron smelted as before, but 1 E.HP.-hour was also furnished, a much higher result than is obtained with most boilers and steam-engines. The furnaces were fired with splint coal, as is usual in Scotland: the gas produced is richer than when coke is used as fuel, and has a relatively high calorific value; consequently the consumption by volume in the gas-engine is lower. Hence, also, the recovery of the tar and ammonia, by-products which are not found in ordinary blast-furnace gases. In the Author's opinion it is essential, when stating the consumption of any kind of gas in an engine-cylinder, to state also the calorific value, whether higher or lower, of the gas used, as determined by a calorimeter. The Junkers calorimeter is the one most used for the purpose.

In consequence of the success obtained at Wishaw, an endeavour was next made to utilize these gases in a similar way at the Frodingham Ironworks. Here the furnaces are fed with coke. A 15-HP. "Acme" engine was started in 1897, and worked successfully. The gas had a calorific value of 102 B.Th.U. per cubic foot, and contained 28·8 per cent. of combustible gases. The consumption was 110 cubic feet per indicated horse-power-hour, showing that gas of low calorific value can be utilized to advantage in an engine-cylinder. This small experimental engine seems to be no longer running.

To complete the account of engines in England working with these gases, mention must be made of the 160-HP. experimental engine at Barrow-in-Furness, where the power furnished was used to generate electric light. The Author has not been able to obtain details of the work of this engine. A 250-HP. single-cylinder "Premier" gas-engine has also been made for blast-furnace gases. This seems to be the largest engine for this work at present in England. A 150-HP. gas-plant has been supplied by the Blast-Furnace Power Syndicate to the Phœnix Hütte

works in Germany.[1] Messrs. Crossley Brothers have constructed a large two-cylinder *vis-à-vis* gas-engine for blast-furnace work, driving direct two blowing-engines also *vis-à-vis*. Thus there are four cylinders, two for air and two for gas, coupled direct to the same crank-shaft, and all making 135 revolutions per minute. A drawing of this engine was inspected by the Author at the Paris Exhibition, 1900. Other large installations are contemplated, but not much appears to have been done in England. Only the Wishaw engine was officially tested, and few data are available. For further information on the subject recourse must be had to the results of continental research and experimental work, both of which are much more complete. Messrs. Cochrane & Co., of Middlesbrough, are now putting up a 600-HP. Cockerill (Seraing) gas-engine.

Next in order of date come the two gas-plants successively worked at the ironworks of the Société Cockerill at Seraing. From the first this was a more important development than the engine at Wishaw, and was, it appears, independently conceived and carried out. At the beginning of 1895 two engineers of the Company, Messrs. Bailly and Kraft, were commissioned by Mr. A. Greiner, the Director, to make trials of various gas-engines, and to select the most suitable kind of engine to construct. Their choice fell upon the "Simplex" engine, and it was while studying the working of this motor with producer-gas that they conceived the idea of utilizing for driving it the gases from their own blast-furnaces, which turn out 600 tons of pig-iron daily. The "Simplex" single-cylinder engine is of the four-cycle kind with electric ignition. It differs from the Otto type internally in the rounded shape of the compression end of the cylinder, which renders it especially suitable for work with blast-furnace gases, as all corners are avoided in which the dust can settle. The engine also carries an ignition slide-valve. Electric sparks are generated continuously in a contiguous chamber, and the valve opens communication with the compression-space of the motor-cylinder. At Seraing the engine is fitted with three inlet-valves. Two are for admitting the gas and air to the mixing-chamber; through the third the charge passes to the cylinder; the latter valve alone, which protects the other two, is exposed to the heat of the explosions, and is water-jacketed.

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[1] Another much larger gas-engine has since been added. A Thwaite-Gardner 400-HP. gas-engine with vertical air-blower has lately been fixed at Clay Cross Ironworks, near Chesterfield.

A small experimental 8-HP. "Simplex" engine was started in December, 1895, and worked about 16 hours daily for 18 months. This was the first trial of an engine driven with gases from furnaces fired with coke, and therefore formed a better fuel-test than the Wishaw experiments. In this small engine, running at half power only, and not primarily intended for blast-furnace gases, the consumption was 187 cubic feet of gas per horse-power-hour. The furnaces were worked at their usual rate of about 1 ton of coke per ton of pig-iron, and the production of gas was about 159,000 cubic feet per ton of iron. The higher calorific value of the gas, as determined by Professor Witz from samples taken daily, was 110 B.Th.U. per cubic foot. It was soon decided to replace this experimental engine by a much larger one, working a François air-compressor; and an engine of 150 B.HP. was started in April, 1898, which has since given excellent results. The difficulty of utilizing blast-furnace gases being once overcome, the power thus obtained was naturally applied to drive the most important machinery for the furnaces, namely, the air-blowers. This "Simplex" motor, which afterwards developed 200 HP., was tested by Professor Witz in July, 1898, and was seen by the Author in July, 1901, when it was at work and running well.

During Professor Witz's tests, which lasted 24 hours, the gas, instead of passing direct to the engine, was conveyed, for purposes of measurement, to a carefully calibrated holder, having a capacity of 10,000 cubic feet. The engine-cylinder has a diameter of 31½ inches, and a stroke of 39·37 inches. The fly-wheel is 13 feet in diameter, and weighs 15 tons. Compression is carried to about 114 lbs. per square inch (8 atmospheres). The results of this trial will be found in the Appendix; the brake horse-power was 181 HP. with about 10 per cent. of miss-fires. The temperature of the exhaust-gases was about 930° F., and the consumption of gas was 116 cubic feet per brake horse-power-hour.

Encouraged by the success obtained, the directors of the Seraing works determined to construct engines on a still larger scale, and they have now made many, as mentioned later. A 600-HP. motor was tested in March, 1900, by Mr. Hubert, under the auspices of Mr. Greiner, and in the presence of many distinguished German, French, Belgian and Austrian engineers. The Author had also the pleasure of witnessing these trials. They lasted 3 days, the tests on the first day being only preliminary. On the second day a brake was applied and the air-cylinder was disconnected; on the third day the brake was thrown off and the

air-cylinder was worked. This is the largest gas-engine which has yet been well tested, coupled direct to a blowing-cylinder. The gas was measured in a holder as before, and its calorific value was carefully determined in three different ways. Samples were first taken every hour during the trials, and tested on the spot by means of a Junkers calorimeter. Other samples were collected in large glass bottles and tested in the Witz bomb calorimeter. Lastly, several samples were taken and analysed at the works in an Orsat apparatus, their composition was determined, and the calorific value was calculated from it. The average calorific value of the gases was found to be 111 B.Th.U. per cubic foot in the Witz calorimeter, and 99 B.Th.U. per cubic foot by the Junkers method. In the Author's opinion the Junkers calorimeter is more accurate, as much larger volumes of gas are dealt with than in the bomb calorimeter. The thermal efficiency of the engine was 31½ per cent. taking the indicated horse-power, and 26 per cent. taking the brake horse-power.

The diameter of the cylinder is 4 feet 3 inches, stroke 4 feet 7 inches; diameter of the air-cylinder 5 feet 7 inches, stroke 4 feet 7 inches; diameter of the through crank-shaft 18 inches, of the fly-wheel 16 feet 5 inches; weight of fly-wheel 33 tons. Total weight of the gas-engine and blower 158 tons; of the engine alone 94 tons. A water-jacket is used, not only to the barrel and end of the cylinder, but also to the end of the motor-plunger piston.

In the first day's preliminary trial the engine indicated 147 HP. and the consumption of gas was 176 cubic feet per horse-power-hour. Details of the main tests, on the two following days, are given in the Appendix. On the third day, with the engine coupled to the blowing-cylinder, two sets of tests were made, with and without miss-fires. With miss-fires the speed was 84 revolutions per minute, the pressure of the air nearly 16 inches of mercury, and the blowing-piston and engine made 168 strokes per minute. Without miss-fires the pressure of air was 18 inches of mercury, the speed 93 revolutions per minute, to-and-fro strokes of the double-acting blowing-piston 186 per minute. Indicator-diagrams were taken from the motor- and air-cylinders. The pressure of air was also determined for different speeds. The engine ran well when the pressure of the blast was suddenly varied from 17 inches to 24 inches of mercury, and the speed fell from 94 revolutions to 62 revolutions per minute. At the moment of explosion in the cylinder, a pressure was exerted of not less than 16 atmospheres, or 213 tons over the surface of the piston; and this was repeated

forty times per minute. Sometimes the pressure was even higher. Since these experiments the engine has been continuously at work.

The Société Cockerill have hitherto constructed only the "Simplex" engine, and it is noteworthy that this important firm should have given their adherence to the single-cylinder engine. Its advocates maintain that it is easier to drive a blowing-engine from a single-cylinder than from a two-cylinder gas-motor; but this appears to be doubtful. According to Mr. M. Münzel, about 250 HP. is the maximum power which it is desirable to develop in a single cylinder. For 1,000 HP. four cylinders are used.

SINGLE-CYLINDER *versus* MULTIPLE-CYLINDER ENGINES.

Whether it is advisable to adopt one or several cylinders for high-power engines is a question still under discussion, which has assumed a new and important phase since the success at Seraing was achieved. The advantage claimed for the single-cylinder engine is that a large plant is free from the complication of many cylinders. Taking, for example, a plant developing 5,000 HP., and consisting of single-cylinder engines each of 1,250 HP., only four motors would be required; while in multiple-cylinder engines developing only 250 HP. per cylinder no fewer than twenty cylinders are necessary. On the other hand, there is a larger reserve of power with the multiple-cylinder engine in case of any mishap. Cylinders of very large diameter require much more care in the jacket-cooling and more water than smaller cylinders. Further, the risk of premature explosion is greatly minimised if ignition be distributed over four cylinders, instead of being confined to one. In the single-cylinder engine, there is only one explosion per two revolutions, or four strokes; whereas in the four-cylinder engine an explosion is obtained at every stroke in one or other of the cylinders, although the cycle is the same. Mr. Münzel gives figures to prove that the weight, and the consumption of gas and of water, are all in favour of the multiple-cylinder as against the single-cylinder engine. The weight of the 600-HP. single-cylinder engine at Seraing is 127 tons, including the fly-wheel; that of a Deutz four-cylinder motor of the same power is 106 tons. As there are four times as many motor strokes, the latter will work with a much lighter fly-wheel. The consumption of cooling-water during the Seraing

trials was undoubtedly high; the consumption of gas was also rather higher than during Professor Meyer's tests at Differdingen; but the calorific value of the blast-furnace gases supplied to the Seraing engine was considerably less (see Appendix). On the whole, the Author fully agrees with Professor Witz that, in order to decide the question, careful experiments should be made, not only on a four-cylinder Otto engine of the same power as the "Simplex engine," and on a 1,000-HP. engine, but also on an Oechelhaüser engine of 600 HP. or 1,000 HP.

In the year 1900 the number of "Simplex" gas-engines in hand at the Cockerill works or already constructed, was approximately as follows:—At Differdingen there was one engine-room containing six 600-HP. single-cylinder gas-engines, with air-blowing cylinders driven direct; also three similar 600-HP. engines, each driving a dynamo direct. In other works there were two 100-HP., three 200-HP., and twenty 600-HP. "Simplex" engines for driving air-blowing cylinders or dynamos direct, and one 1,200-HP. engine with air-blowing cylinder coupled.

Messrs. Schneider & Co., the makers of the "Simplex" engine in France, had in hand or already at work the following gas-engines: one 100-HP., six 200-HP., two 250-HP., and eleven 600-HP., either for blowing air or for driving dynamos direct. For the same purposes the following firms had "Simplex" gas-engines in hand or working, viz., Société Alsacienne, Mulhouse, three 200-HP. and three 600-HP. engines; the Märkisch Maschinenbau-Anstalt, Germany, three of 200-HP., one of 600-HP. and two of 1,200-HP.; and Messrs. Breitfeld, Danek & Co., Austria, one 250-HP. and four 600-HP. engines.

Among the countries which are utilizing this new motive power, and in which engines working with blast-furnace gases have been particularly studied, Germany occupies a foremost position. The first engine so driven was started at the Hörde Ironworks in Westphalia, in the same year as those at Wishaw and Seraing. In October, 1895, the authorities began experiments on a 12-HP. Otto engine driven with blast-furnace gases having a (lower) calorific value of 112 B.Th.U. per cubic foot, and running at 200 revolutions per minute. The diameter of the cylinder was 9 inches, the stroke 13 inches. The consumption of gas was 141 cubic feet per brake horse-power-hour, and the engine gave 13 B.HP. with power-gas and 10·5 B.HP. with blast-furnace gases, with a compression of 6½ atmospheres. In the three small engines thus started independently in the same year at Wishaw,

Seraing and Hörde, the consumption of gas was naturally in excess of what it is now. Such small motors are out of place in ironworks, where the volume of gas generated hourly is so considerable that large engines working economically are required. At Hörde the results obtained were so satisfactory that the authorities, foreseeing a great future for this class of work, soon determined to adopt much larger powers. A two-cylinder 600-HP. motor was proposed, and a two-cycle engine, the Oechelhaüser, built by the Berlin-Anhaltische Maschinenbau-Aktien-Gesellschaft, was selected. Several of these are now working well.

The Oechelhaüser Gas-Engine.

As already mentioned, the Oechelhaüser two-cycle engine, now made by the Deutsche Kraftgas-Gesellschaft, has hitherto been worked with blast-furnace gases only. It has one long horizontal motor-cylinder with two pistons working in opposite directions, as in the Atkinson differential engine, and a small air-cylinder, driven from the back cross-head. The two motor-pistons work on the same crank-shaft through three cranks, 180° apart. There is no auxiliary or cam-shaft, and there are practically no valves, the admission and exhaust ports round the cylinder being opened and closed by the two pistons, as in some other engines. The size of the exhaust openings is carefully adjusted, and they are large enough to prevent the products of combustion from remaining in the cylinder. A scavenging charge of air cleanses the cylinder from the products of combustion, and helps to keep it cool. The cycle of the engine is as follows:—

The two motor-pistons being close together, when the space between them, into which the charge is compressed, is smallest, the mixture of gas and air, at a pressure of about 8 atmospheres, is fired electrically, and the force of the explosion drives the two pistons apart, both doing work upon the crank-shaft. During this stroke one side of the double-acting air-pump takes in a fresh charge of air and compresses it slightly into the air-chamber and passage, whence it passes later, as required, into the compression-space between the two pistons of the motor-cylinder. Meanwhile, the other side of the air-pump draws in a mixture of gas and air through a passage and a cock controlled by the governor, and delivers it, with the air and at the same pressure, through a separate inlet into the compression-space. The two

motor-pistons are by this time nearly at the end of their stroke, and farthest apart. One of them then uncovers the exhaust ports, and the products of combustion escape into the exhaust pipe. Immediately after, the other piston uncovers the air-port, and fresh cool air, at a pressure sufficient to render it an effective scavenging charge, sweeps through the cylinder, driving out the products of combustion. Lastly, this second piston uncovers the gas- and air-openings, the charge, already slightly compressed by the pump-piston, enters the motor-cylinder and is compressed between the two pistons during their return stroke, and the cycle recommences.

Thus the operations of admission, compression, explosion, expansion, and discharge of the products of combustion are all carried out in two strokes or one revolution. Care is taken to prevent the escape of any of the fresh charge with the burnt products. The governing of the engine was not satisfactory when the Author saw it at work. The speed is now regulated by varying the quality of the charge, and is said to be maintained uniform by adjusting the quantity of gas admitted, and thereby the proportions of the mixture to the load. The long cylinder is fitted with a water-jacket, and has no sharp corners in which the dust can settle. The scavenging charge of air, which at Hörde is drawn from the air-pipe of the blowing-engines, helps to cool the cylinder, and to drive out any dust which may have been brought in by the furnace-gases. The engine seems to be well adapted to work with these gases, and it is said to give four times as much power as a four-cycle motor of the same dimensions. For an engine developing 1,000 HP. a cylinder only 36·8 inches in diameter is required.

The 600-HP. engine at Hörde consists of two 300-HP. single-cylinder engines, coupled; each cylinder is 19 inches in diameter by 31·5 inches stroke. Thus there are two cylinders and four pistons driving a dynamo on the crank-shaft with six cranks. The speed is about 135 revolutions per minute. The Author has seen this engine at work. The consumption during the preliminary tests was said to be about 108 cubic feet of gas per brake horse-power-hour. There are now three 600-HP. two-cylinder Oechelhaüser engines at work at Hörde, and it is proposed to have four in all. Several other large engines on this system are in course of construction by the Deutsche Kraftgas-Gesellschaft. To provide the air-blast, the small air-pump may be replaced by the usual large air-blowing cylinder, and the rod be coupled direct to the back cross-head. Eight two-cylinder side-by-side engines developing 1,000 HP. and in-

tended to drive dynamos, and four single-cylinder 500-HP. engines intended to drive air-blowing cylinders, are being or have been erected at other German works, all using blast-furnace gases. A single-cylinder 1,000-HP. engine developing a maximum of 1,200 HP. is also intended to be made. The diameter of the cylinder will be 3 feet $3\frac{3}{8}$ inches, and the engine will run at 100 revolutions per minute. It is also proposed to construct later single-cylinder engines of 1,500 HP. to 2,000 HP.

The Berlin-Anhaltische Maschinenbau-Aktien-Gesellschaft made the four-cycle 60-HP. engine at Differdingen, upon which Professor Meyer carried out one of the best trials yet undertaken with these gases. The engine was practically the same as one built for lighting- and power-gas, but the compression-space was smaller, being about one-sixth of the total volume of the cylinder, and the gas- and air-passages had been modified. A pump drew the gases from the blast-furnaces and sent them through the gas-cleaners to the gas-holder. The charge was fired electrically. An illustrated description of the trial, which took place on two consecutive days in October, 1898, will be found in the Journal of the Society of German Engineers.[1] The consumption of gas was calculated from the fall of the holder, and both temperature and pressure of the gas were noted. Its (lower) calorific value, determined with great care in a Junkers calorimeter, worked out at 105 B.Th.U. per cubic foot, corrected for temperature and pressure. The diameter of the cylinder was 17 inches, and the stroke 27·6 inches, the average speed being 161 revolutions per minute. Further details of the trial will be found in the Appendix.

The consumption of gas per indicated horse-power-hour and per electrical horse-power-hour was the lowest yet obtained. The thermal efficiency was, taking the indicated horse-power, 30·2 per cent.; taking the electrical horse-power, 25 per cent.; the heat lost to the jacket-water was 24·3 per cent.; in the exhaust and by radiation 45·5 per cent. All the instruments used in the trial were carefully calibrated, and indicator-diagrams were taken every 5 minutes. This programme was adopted in order to get exact data of the work of the engine, including miss-fires, of which there were about 1 in 9. The diagrams, taken one over the other, showed the regularity of the working of the engine, and thus the fears entertained as to the effect of the varying composition of the

[1] Zeitschrift des Vereines deutscher Ingenieure, vol. xxxiii. p. 483.

gases were found to be groundless. When Professor Witz tested the same engine, the thermal efficiency, taking the brake horse-power and the higher calorific value of the gas, was 21·5 per cent., showing that a comparatively small engine can be driven advantageously, and with good results, with cooled but not specially cleaned gas.

An interesting series of experiments was made by Mr. Köhler in December, 1898, at Duisburg, on a 40-HP. engine driven with blast-furnace gases. The diameter of the cylinder was 14·5 inches, stroke 20·4 inches, speed 182 revolutions per minute. The weight on the brake was varied, and the consumption of gas was determined at different loads. Many indicator-diagrams were taken, and the mean calorific value and analysis of the gas were determined; also the composition of the exhaust gases, the quantity of cooling-water, and the temperatures of gas, air, cooling-water, and exhaust gases. In the first experiment the brake horse-power was 39·5, the indicated horse-power 49·4; the consumption of gas having a calorific value of 106 B.Th.U. per cubic foot was 99 cubic feet per brake horse-power-hour. The thermal balance showed: heat turned into indicated work 29·82 per cent.; heat carried off, in the cooling-water 33 per cent., in the exhaust 26·95 per cent.; heat lost by imperfect combustion 6·82 per cent., by radiation, etc., 3·4 per cent. At the smaller load of 105·2 kilograms on the brake the results were rather better, namely, consumption of gas 98 cubic feet per brake horse-power-hour; calorific value of the gas 108·4 B.Th.U. per cubic foot; thermal efficiency, taking the indicated horse-power, 29·9 per cent. A third experiment gave 28·9 B.HP.; 38·7 I.HP.; consumption of gas 107 cubic feet per brake horse-power-hour; (lower) calorific value of gas, 112·3 B.Th.U. per cubic foot; calorific efficiency, taking the indicated horse-power, 28 per cent. At half load the brake horse-power was 21·7; indicated horse-power 31·7; consumption of gas, 126 cubic feet per brake horse-power-hour; calorific value 110·4 B.Th.U. per cubic foot; thermal efficiency, taking the indicated horse-power, 27 per cent. These results show again that with suitable compression a high thermal efficiency can be obtained with these gases of low calorific value.

The Gasmotoren-Fabrik Deutz seems to have made more engines to work with blast-furnace gases than any other works. Besides the 12-HP. engine already mentioned, a large plant, of great interest from an experimental point of view, has been started by this firm

at the Friedenshütte Ironworks in Upper Silesia. A small engine was put up in 1897, and, after many difficulties due to the dust in the gases, the Company succeeded in getting it to work so well that a 1,000-HP. plant has now been erected. It consists of four two-cylinder engines, two of which, of 200 HP. each, have been working satisfactorily for 18 months. At full load their consumption of gas having an average calorific value of 106 B.Th.U. per cubic foot was 123 cubic feet per horse-power-hour. The other two engines develop 300 HP. each, or 150 HP. per cylinder, and were started in April, 1899. All are coupled direct to dynamos. They are regulated in the same way as steam-engines, the governor controlling the supply of gas and air to each cylinder if the normal speed is exceeded.

Messrs. Crossley Brothers have made for Wolverhampton a 500-HP. gas-engine, using the gases from blast-furnaces, and driving air-blowing cylinders direct.[1] Blast-furnace gases are to be utilized near Essen in Germany for the manufacture of calcium carbide, and two gas-engines, giving about 2,000 HP., are being made in Germany.

Not much appears to have been done in the United States, where a store of natural gas is still available for power. The Westinghouse gas-engine, however, which is made at present up to 1,500 HP., will probably be adapted for use with blast-furnace gases, although it does not seem to have been so employed hitherto.

It will thus be seen that this new source of motive power, the application of which the Author has studied in many places and has here endeavoured to trace, is already largely utilized on the Continent. The development of its application in many directions is rapid, and is certain to increase. In 5 years, between 1895 and 1900, gas-engines using blast-furnace gases have grown in size from 10 HP. to 1,000 HP.; and Mr. Hubert estimates that the total power produced in this way will shortly be 100,000 HP. The subject is therefore one which deserves to receive the earnest attention of English gas-engineers, iron-masters and capitalists; and the Author trusts that his remarks may contribute to this desirable end.

The following Table gives a summary of the progress realised between 1895 and 1899:—

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[1] See *The Engineer*, vol. xci. p. 345, for details and illustration.

GAS-ENGINES WORKING WITH BLAST-FURNACE GASES.

Date.	Place.	Name of Engine.	HP.	Remarks.
February, 1895	Wishaw	Acme	20	(Thwaite) tested by Booth, 1896.
October, 1895	Hörde	Otto	12	Experimental engines.
December, 1895	Seraing	Simplex	8	
June, 1896	Hörde	Oechelhaüser	120	Two-cycle engine.
1897	Frodingham	Acme	15	..
1897	Friedenshütte	Deutz	..	Small experimental engine.
April, 1898	Seraing	Simplex	200	Tested by Prof. Witz.
May, 1898	Hörde	Oechelhaüser	600	First engine; second started January, 1900.
Spring, 1898	Johannishütte	Krupp	40	Tested by Köhler, December, 1898.
October, 1898	Differdingen	Otto	60	Tested by Meyer, October, 1898.
January, 1899	Friedenshütte	Deutz	200	Two engines, each of 200 HP.
August, 1899	Donnersmarck	Körting	100	..
November, 1899	Seraing	Simplex	650	Tested by Hubert, March, 1900.

ADDENDUM.

In March, 1901, Mr. Lürmann read a Paper[1] before the meeting of the Association of German Iron-masters at Düsseldorf, which is too important to be passed over in silence, although only a brief summary of it can be given here. After reviewing the objections to the use of blast-furnace gases in gas-engine cylinders for the direct production of power, Mr. Lürmann states that most of them have been obviated, with the exception of the dust with which the gases are charged. There has never been much difficulty in getting rid of the heavy metallic dust, which settles almost immediately in the long pipes; it is the light volatile dust which in most cases has hitherto formed the main obstacle to the direct utilization of these gases. After glancing at the different methods of purification in use at the Friedenshütte, the Gutehoffnungshütte, the Georg-Marienhütte, and elsewhere in Germany, and at Differdingen and Dudelingen in Luxemburg, Mr. Lürmann describes the process adopted in the large works at Differdingen (which the Author visited recently), and mentioned by Mr. Greiner, namely, that of passing the gases successively through two fans provided with water-jets. He heartily endorses Mr. Greiner's

[1] *Stahl und Eisen*, 1901, Nos. 9 and 10.

opinion as to the merits of the fan method, and considers that the adoption of this simple, economical, and efficient system of purifying the gases marks a new advance in blast-furnace work. In his opinion the direct utilization of these gases in gas-engines is no longer a mere possibility, but is a certainty; because of the ease with which the dust can be removed and the gases can be cleansed and cooled, by means of fans with water-injection; a method which, he urges, should receive the attention it deserves. The systems of purification adopted in various German ironworks are shown in tabular form. Mr. Lürmann next considers the present arrangements for driving air-blowing cylinders direct from gas-engines, and gives some statistics of the progress made in this direction in Germany, where 58 per cent. of all the power obtained from the utilization of blast-furnace gases is developed. The Deutz firm provides 10,120 HP., the Oechelhaüser engines develop 12,800 HP., the "Simplex" by the Société Cockerill, of Seraing, 9,900 HP., and Messrs. Körting Brothers and another firm 11,800 HP.; thus the large total of more than 44,000 HP. is now generated in Germany from blast-furnace gases. The Seraing firm have supplied 7,600 HP. in Belgium, 7,400 HP. in France, and 1,800 HP. in Italy. Drawings of numerous engines are given in Mr. Lürmann's Paper. The largest engine at present made is a single-cylinder motor in Germany giving 750 HP., or 1,500 HP. when arranged tandem. Four of these tandems combined would give 6,000 HP.

[APPENDIX.

APPENDIX.

Tests of Gas-Engines working with Blast-Furnace Gases.

Nine tests on four different single-cylinder, four-cycle gas-engines, Belgian and German, arranged in order of merit of the thermal efficiency calculated on the brake horse-power. (Metric horse-power = 2 per cent. less than English.)

No.	Name of Gas-Engine and Maker.	Name of Experimenter.	Place.	Year.	Gas-Engine Cylinder.		Mean Revolutions per Minute.	Horse-Power (Metric).		Mechanical Efficiency.	Thermal Value Gas, B.Th.U. per Cubic Foot.	Gas Consumed per Hour		Heat used in B.Th.U. per Minute		Thermal Efficiency.		Remarks.
					Diam.	Stroke.						Per I.HP.	Per B.HP.	Per I.HP.	Per B.HP.	I.HP.	B.HP.	
					Ins.	Ins.	Revs.	I.HP.	B.HP.	Per Cent.		Cubic Feet.	Cubic Feet.	B. Th.U.	B. Th.U.	Per Cent.	Per Cent.	
1	"Simplex" Cockerill	Hubert[1]	Seraing	1900	51	55	93	886	725	82	97 lower	83	101	134	163	31½	26	Blowing-cylinder coupled direct; air-pressure, 7¾ lbs. per square inch.
2	Berlin-Anhaltische Maschinenbau-Aktien Gesellschaft	Meyer[2]	Differdingen	1898	17	27½	160	79½	67½	85	105 lower	79½	93½	139	164	30	25	Driving dynamo by belt. Full-power test.
3	Berlin-Anhaltische Maschinenbau-Aktien Gesellschaft	Meyer[2]	Differdingen	1898	17	27½	160	79	66	84	105 lower	80·7	96	141	168	30	25	Driving dynamo by belt. Full-power test.

4	Krupp	Köhler[3]	Duisburg	1898	14½	20½	182	49½	39½	80	{106 lower}	124	99	..	..	30	23·8	Full power.
5	Krupp	Köhler[3]	Duisburg	1898	14½	20½	184	38¾	29	74½	{115 lower}	143	107	..	..	28	21	Less power than No. 4.
6	Berlin-Anhaltische Maschinenbau-Aktien Gesellschaft	Meyer[2]	Differdingen	1898	17	27½	162	46½	62	75	{106 lower}	86¾	116	153	206	27	20½	Half power; two other experiments, Nos. 2 and 3.
7	"Simplex" Cockerill	Hubert[1]	Seraing	1900	51	55	94½	786	575	73	{101 lower}	91	124	153	209	27	20	Test with brake on same engine as No. 1.
8	"Simplex" Cockerill	Witz[4]	Seraing	1898	31½	39½	105	..	182	..	{110 higher}	..	116	..	213	..	20	Driving dynamo by belt.
9	Krupp	Köhler[3]	Duisburg	1898	14½	20½	184	31¾	21¾	65	{110 lower}	194	126	..	..	27	17½	Same engine as Nos. 4 and 5, about half power.

[1] Bulletin de la Société de l'Industrie Minérale, 3rd series, vol. xiv. p. 1461.
[2] Zeitschrift des Vereines deutscher Ingenieure, vol. xxxiii. pp. 448, 483.
[3] *Ibid*, vol. xxxiv. p. 1213.
[4] Witz, "Traité théorique et pratique des Moteurs à Gaz et à Pétrole," vol. iii. p. 214.

Discussion.

The President. The PRESIDENT moved a vote of thanks to the Author for his interesting and valuable Paper, which, he thought, foreshadowed the great economy to be secured by the use of blast-furnace gases in gas-engines in ironworks.

The Author. The AUTHOR observed that since the Paper had been printed, Mr. J. Kraft, M. Inst. C.E., of the Société Cockerill, had sent him the following analyses of blast-furnace gases and of the dust at Seraing. From the data as to the gases their average calorific value at Seraing might be calculated. The heavy metallic particles of dust were deposited in the long pipes from the blast-furnaces, and there was very little left at the end of those pipes. The Author then exhibited some lantern-slides illustrating gas-engines using blast-furnace gases.

MEAN COMPOSITION OF BLAST-FURNACE GASES AT SERAING.

	Per Cent. by Volume.
CO_2	9·5
CO	26·5
H	1·0
CH_4	1·5
N and H_2O	61·5
	100·0

ANALYSES OF DUST IN THE GASES AT SERAING (NOVEMBER, 1901).

—	Grey Dust in the Main Gas-Pipes.	White Dust from the Cowper Stoves.	White Dust from the Boiler-Flues.
	Per Cent.	Per Cent.	Per Cent.
Loss at the fire	8·40	0·50	3·50
Silica ($Si\,O_2$)	11·60	21·10	18·40
Alumina ($Al_2\,O_3$)	5·30	6·70	4·80
Lime (Ca O)	4·00	9·50	14·60
Magnesia (Mg O)	0·50	2·00	2·35
Zinc oxide (Zn O)	3·75	7·75	4·35
Lead oxide (Pb O)	3·30	6·90	6·40
Ferric oxide ($Fe_2\,O_3$)	39·00	14·70	19·45
Ferrous oxide (Fe O)	16·30	1·80	0·0
Manganous oxide (Mn O)	0·50	1·50	1·60
Sulphur (S)	1·05	0·75	0·15
Alkalies soluble in water	0·20	7·20	7·50
Alkalies insoluble in water and sulphates, with a few chlorates	5·80	18·90	16·90
Total	99·70	99·30	100·00

Mr. HORACE ALLEN remarked that during the last 30 years he had been engaged in the metallurgy of iron and steel, and, of all the advances made in the economical production of pig-iron, not one had attained such prominence in so short a time as that relating to the application of the large volumes of gas issuing from the top of the blast-furnace to the direct development of power in internal-combustion engines, which had been so rapidly extended since the date of Mr. B. H. Thwaite's pioneer work in 1894. For many years he had been associated with Mr. Thwaite, and his own experience in blast-furnace work enabled him to appreciate the importance of the invention in connection with the economical production of pig-iron; and already he had had experience in the application of blast-furnace gases to installations developing between 5,000 HP. and 6,000 HP. in Great Britain and on the Continent. The Author gave the total annual output from blast furnaces all over the world as 40,000,000 tons of pig-iron, a rate of production of 4,566 tons per hour. At a fuel-consumption of 1 ton of coke per ton of pig-iron, with a production of 170,000 cubic feet of gas, the total volume of gas per hour worked out at 776,220,000 cubic feet; this, at 120 cubic feet per indicated horse-power-hour in internal-combustion engines gave a total of 6,468,500 I.HP.-hours. But even now there were many furnaces of the open-top kind, which allowed a large quantity of gas to escape into the atmosphere, while more or less coal had to be used to keep up the supply of steam; whereas, if the furnace-top were closed and the gas were used in gas-engines there would be a large excess of power which could be profitably applied, over and above that necessary for the requirements of the furnace, even after allowing for the heating of the blast. The change in the calorific value of the gas from hour to hour, to which the Author referred, was not considerable, and would compare favourably with any other source of heat, especially if comparison were made with, say, Dowson gas. With regard to the ratios of the volumes of CO_2 and CO mentioned in the Paper, viz., 58 per cent., 70 per cent., and 50 per cent., examination of a large number of analyses of gas from blast-furnaces in Great Britain, on the Continent and in the United States, gave 47 per cent. as the highest ratio, 40 per cent. being more common. The volume of gas produced should be described as proportional not to the output of pig-iron, but more correctly to the weight of fuel consumed in a given time; though, of course, the oxygen derived from the ore affected the volume. Referring to the difference in the capabilities Mr. Allen.

Mr. Allen. of an engine with lighting-gas and with blast-furnace gas respectively, the Author cited an instance in which the power developed with the latter gas was 18 per cent. lower than that from lighting-gas in the same engine, but he then gave figures showing a ratio of 584 : 400, which would indicate a difference of 31 per cent. In the latter case, however, the effect of the higher compression employed when using the power-gas was not taken into account in the calculation, and it was probable that the difference would be rather under than over the 18 per cent. mentioned where compression was carried to its most efficient stage. As the Author pointed out, the chief difficulty to be overcome was the dust carried by the gases, which, after very considerable trials and experience, had been found to necessitate the provision of special apparatus, even when the amount of dust was as low as 2 grams per cubic metre (0·9 grain per cubic foot). In the installations on the Thwaite-Gardner system the gas was freed from dust and otherwise reduced to a condition most advantageous for use in gas-engines; that was, dust and tar were removed, moisture was reduced to its lowest point and temperature to that of the atmosphere or lower, and the pressure was constant. The removal of moisture was a most important point, and where the gas was passed through a series of washing-pans only, the high proportion of moisture would greatly affect the ignition and the efficiency. The principal ingredients found in some dust which had accumulated in the combustion-chamber of a stove, and which represented roughly that carried along by the gases, had been found to be, oxide of iron 37·4 per cent.; alumina 7·2 per cent.; lime 17·0 per cent.; and silica 20·0 per cent. As indicating the almost uniform quality of the gas, it might be pointed out that in the Author's figures showing the average calorific value of gases from various furnaces, using different classes of fuel, ore, and flux, the greatest difference was only 6 per cent.; four samples from a single furnace gave a maximum difference, probably never exceeded, of 5 per cent. Probably the chief reason why no successful method had been found of freeing the gas from dust before it was used in boilers and stoves was that this could not be done effectively without cooling the gas and saturating it with water, thus rendering it almost incapable of combustion at atmospheric pressure. Cooling was necessary before the gas could be used economically in gas-engines, and then a high degree of compression was needed. For combustion at atmospheric pressure, the gas should be kept as hot as possible, and all precautions should be taken to prevent loss of heat. Reference

had frequently been made to the fact that at Seraing the gas used Mr. Allen. in the gas-engine was drawn from the pipe which supplied the boilers, but it was not usually explained that the total distance travelled by the gas was 284 yards (260 metres); so that, besides the complete cooling-apparatus proper, there was a large surface of tubing. The hot gas, on leaving the furnace, carried considerably more moisture than it could hold when at atmospheric temperature, and the condensation of this moisture, due to cooling during the passage of the gas along the tube, carried down a considerable portion of the dust. Unless the tubing between the furnaces and boilers was brick-lined, the gas, which would ignite better if it retained its sensible heat, must be very considerably cooled, and in many cases even the hot gas ignited with difficulty in boilers and stoves, under unfavourable conditions of draught. At the Königshof Ironworks in Bohemia, where the gas was said to contain only the very low quantity of 2 grams of dust per cubic metre (0·9 grain per cubic foot), it was found necessary to use suitable scrubbers; and even then the cleaned gas contained 0·6 gram of dust per cubic metre. At the Sheepbridge Ironworks, near Chesterfield, the gases carried as much as 12 grams of dust per cubic metre (5·25 grains per cubic foot), all of which was removed by the Thwaite-Gardner apparatus. In speaking of starting large gas-engines, no reference was made by the Author to the method of using a small auxiliary gas-engine. In the Thwaite-Gardner installation that had been found very effective, large engines being readily started by a friction-pulley acting on the fly-wheel. The auxiliary engine could, of course, be made to start several engines in one house, and be run only when required. In regard to the driving of blowing-cylinders direct from a crank on the same shaft as the gas-cylinders, that was the arrangement adopted on the engine at the Clay Cross Ironworks, constructed by the Blast-Furnace Power Syndicate. Two gas-cylinders, on the same side of the crank-shaft, actuated a vertical single-acting blowing-cylinder by a third crank and connecting-rod. To suit the high speed of the gas-engine—160 revolutions per minute—a system of valves, devised by Mr. J. W. Gordon, had been applied and had worked very satisfactorily. In the description of the "Simplex" engine in the Paper it was claimed that the rounded shape of the compression end of the cylinder prevented dust from settling, but so far he had not had any settlement of dust whatever in the combustion-chamber, with gas treated by the Thwaite-Gardner system. On the question of

Mr. Allen. single-cylinder *versus* multiple-cylinder engines, he would point out that in a single-cylinder engine of 1,250 HP., the cylinder would have to be about 6 feet in diameter if the Otto cycle was adopted, while the force of the explosion on its large area would be about 450 tons, which proportions, he thought, would not commend themselves to engineers, especially when the inertia-effects were taken into account. At Sheepbridge, during the violent storm on the night of the 13th December, 1901, the pipe-foundry, which was dependent for its power and light upon the continuous and efficient working of an engine using blast-furnace gas, had been almost the only department not interrupted in some way or rendered almost inoperative; the high wind having interfered with the usual method of burning the gas under boilers and in stoves, through its effect on the draught.

Mr. Denny. Mr. T. J. DENNY, referring to the Author's remark that time and experience alone would show whether engines driven with thoroughly purified gases did more work and wore better than those in which only partly cleaned gas was used, considered it certain that the hard coke-dust and mineral dust must in time act erosively on the cylinders. Although it might be possible to work even for months with gas containing a relatively small quantity of the suspended dust, the cylinder-lining would eventually suffer, and the efficiency of the engine would fall, because on explosion occurring the gas would escape past the piston in larger and larger quantity as the erosive effect increased. There could be no question that proper study of the purification of the gases had been overlooked by the continental builders of gas-engines, who had rushed into competition with each other, with the result that serious difficulties had soon been encountered. These difficulties and the conflicting statements about the cleansing of the gases had contributed largely to the delay which in this country was always experienced in adopting a new departure from established practice. But iron-masters must now realize that thorough purification was essential and could be effected, and that the importance of securing this made the question of first cost a small one compared with that of working continuously and satisfactorily with the large installations that would become universal, and in which any stoppages due to improperly purified gas would be productive of serious results. In referring to the experiences at Seraing, the Author stated (p. 11) that the gas contained about 10 grams of heavy dust and 2 grams of light dust per cubic metre; but in referring later to the difficulties which had occurred at Differdingen in a Seraing type of engine, he

stated that at Seraing they had to deal with only ¼ gram to Mr. Denny. ½ gram of dust per cubic metre. A reduction from 12 grams to between ¼ gram and ½ gram per cubic metre hardly justified Mr. Greiner's widely published statement that no purification of the crude blast-furnace gas was necessary.[1] Such gas, when cleansed and freed from its sensible heat, was obviously no longer crude. The difference in calorific value had already been stated by Mr. Thwaite at the Glasgow Engineering Congress. It was further stated in the Paper that at Differdingen difficulties had occurred when this theory had been put to test, but that eventually good results had been obtained by passing the gases through two fans, into which water was admitted. The Thwaite-Gardner plant had, as an essential feature of the system, a high-pressure centrifugal fan, which had a capacity four or five, or even more, times as large as the engine required. By means of a mercury return-valve actuated by the holder, the excess of gas was returned to the fan, which, working at 1,500 revolutions to 2,000 revolutions per minute, provided a more perfect centrifugal effect than any low-speed fan or fans. But even this perfection of the system of centrifugal action was not complete in its cleaning influence, as the bombardment of the particles prevented the absolute separation of the dust, and double filtration was added, whereby, not only were the remaining particles caught, but any water remaining was removed from the gas; so that the full explosive effect, which the moisture, if carried into the cylinder, would otherwise influence adversely, was obtained. From his examination of the continental systems, he thought they were all modifications more or less of the Thwaite-Gardner system. The Theisen apparatus had been working when he saw it, but he had been able to get no exact data, nor to hear of any other applications; and while it might form a useful element of a plant for thoroughly preparing blast-furnace gas for use in gas-engines under the best conditions, he could not conceive of its fulfilling that function alone. The blast-furnace gases referred to as being utilized for the manufacture of calcium carbide near Essen were

[1] See Greiner, "A Blowing-Engine worked by Blast-Furnace Gas," Journal of the Iron and Steel Institute, 1900, vol. lvii. foot-note, p. 110, and Mr. James Riley's remarks in the discussion on Mr. Greiner's Paper on "Dust in Blast-Furnace Gases," *ibid.* 1901, vol. lix. p. 62. See also publication of the Société Anonyme John Cockerill entitled "Moteurs à Gaz de Hauts-Fourneaux," p. 5: "Depuis cette époque un moteur fonctionne jour et nuit avec *le gaz brut tel qu'on l'emploie actuellement aux chaudières.*"

Mr. Denny. purified by the Thwaite-Gardner system, and the installation was estimated to treat sufficient gas for engines aggregating 4,000 HP. The first calcium carbide produced by means of power from furnace-gases had been made by the 150-HP. engine at the same works, the Phœnix Hütte, referred to by the Author.

Mr. Brown. Mr. ANDREW BROWN observed that he had had the pleasure of visiting the works at Differdingen in the preceding July, and he could not speak too highly of the beautiful installation there. Everything seemed to be working in perfect harmony. The manager, Mr. Meier, had informed him that there was absolutely no trouble with the dust in the gas when it arrived at the engines, and that between 5,000 HP. and 6,000 HP. was being developed at practically no cost. With regard to the Author's explanation of the system of purifying the gases at Differdingen and his statement that to reduce the quantity of dust from 4 to 5 grams per cubic metre to about $\frac{1}{4}$ gram per cubic metre necessitated the employment of two centrifugal fans, he thought it could not be too clearly stated that the gases passed first through one fan and then through the other. In the first fan something like 4 grams or $4\frac{1}{2}$ grams of dust per cubic metre was removed, and the water issuing from that fan was of a milky turbid nature, having the appearance of being largely impregnated with lime. The gases next passed to the second fan and received a further supply of water, and then passed on to the engine with about 0·1 gram, or even only 0·05 gram of dust per cubic metre. It was necessary to have the gases as pure as possible. It was true also that to lose the sensible heat in the gases by admixture with water was not theoretically correct; but he thought the matter must be left largely in the hands of the blast-furnace owners, who would no doubt adopt the most economical system for removing the dust from the gases. The centrifugal fan as a machine was reliable, was not very costly, and seldom got out of order; and at Differdingen it had proved itself a most effectual means of removing the dust. It was very much cheaper than any system of dust-chambers. The plant of the steelworks at Differdingen was entirely new. At these works not only were the blast-furnace gases utilized, but the finest system of rolling-mills in the world was being put down. It was intended to roll steel girders 12 inches by 12 inches, and also to roll them 30 inches by 12 inches, so that in course of time girders of these dimensions would be obtainable. The Paper was substantially a record of facts which the Author had succeeded in gathering, and it clearly showed that the utilization of blast-furnace gases as a more economical

means of production must be adopted by this country as soon as possible if the country was to keep abreast of the times and meet foreign competition. Mr. Brown.

Mr. G. J. SNELUS asked what difference there was in value between the gases from the ordinary blast-furnace consuming coke, from a furnace consuming raw coal, as in Scotland, where the tar and oils were collected, and from a blast-furnace consuming raw coal where the tar and the oils were not collected. He would suppose that the gas from the last-mentioned furnace would be the most valuable for internal-combustion engines, and in conversation with the Author he had gathered that that was so. Being connected with furnaces burning raw coal, in which the tar and ammonia were not collected, he was interested in the subject. He wished also to defend his old friend Mr. Greiner. According to a previous speaker Mr. Greiner had stated that the dust in the gases did not matter, and the same thing had been alleged on two or three occasions elsewhere; but he did not believe that Mr. Greiner had ever said that. He had studied Mr. Greiner's statements very carefully, and he believed that what that gentleman had really said was that the gases from the furnaces at Seraing were used as they came off, with the amount of cleaning it was usual to give to the gas going to the stoves. That gas was much better cleaned than the gas in most ironworks, and therefore could be used without any trouble. The dust in blast-furnace gases contained several different substances such as silica, rough particles of iron ore, and particles of coke carried over with the blast; but there were other substances in it which he thought were due to volatile bodies; and some of these, and even some of the oxide of iron, were probably valuable as lubricators. It was well known that hematite ore was one of the best polishing materials that could be obtained, and it was quite possible that a large portion of the dust acted as a lubricator in the cylinders, and to some extent mitigated the effect of the coarser particles of the dust, even when the gases were not cleaned. Still, the gas was better when thoroughly cleaned, and he thought it was a point of great importance to all iron-masters that the simple method of employing a fan and a jet of water did effectually remove the bulk of the dust, and enabled the gas to be used in internal-combustion engines. He believed the invention was one of the utmost importance, more important, in fact, than any invention in iron and steel manufacture during the past 10 years; and he thought the industrial world was on the threshold of an enormous advance in the use of gas from blast-furnaces. The quantity generated in Mr. Snelus.

Mr. Snelus. a blast-furnace was so large that the fuel consumed could not only do the whole of the work required in the ironworks and steelworks, but should also be able to produce largely power for use outside the works.

Mr. Blount. Mr. BERTRAM BLOUNT remarked that for some time these attenuated gases had been thought to be scarcely usable except for burning under boilers, and when it had been found that their use in an internal-combustion engine was perfectly feasible, and that combustion took place smoothly and with high efficiency, the iron-masters had begun to open their eyes, and some of them had opened them to a great deal of purpose. Correlative with that there had been the advance and enlargement of the modern gas-engine, power being now generated on a scale comparable with that of the largest steam installations with which he was acquainted. It followed that there would be produced at all the large ironworks throughout the country and abroad a vast amount of power for which there was no pressing or immediate use; that after a part of it had been disposed of in running blowing-engines, hauling-gear and the like, there would be a surplus; and as the efficiency of the collection and screening of the gas improved, and as the efficiency of the gas-engines themselves increased, the surplus would become greater, and it would be discovered that a large amount of power existed which the iron-masters did not know what to do with. That seemed a lamentable state of things, but, on proper examination, he thought it would be found a satisfactory and useful condition. He was consulted frequently as to the utilization of power which was vastly in excess of the ordinary requirements, and he had one staple answer which, he ventured to think, was sound. He advised that the power should be turned to account in electro-chemical industries. There were no industries which required power in such quantities; 2,000 HP. for ordinary manufacturing purposes was thought large, but it was only a unit in electro-chemical industry. That kind of large utilization of power was just the thing the iron-masters could do, and he looked forward confidently to the time when attached to every ironworks there would be not only a chemical or recovery works, as there was even now, but a large manufacturing concern using the surplus power to make electro-chemical products.

, Davey. Mr. HENRY DAVEY wished to express the satisfaction it was to him as a mechanical engineer to watch the development of the gas-engine. With regard to blowing-engines, the speed was stated in the Paper to reach 130 revolutions per minute, which seemed to him a very high speed for the ordinary valves of a blowing-

engine; and he would be glad to know whether any particular kind of valve was used for such excessive speed. It appeared to him that the designers of gas-engines had a great deal to do in the way of improvement. It seemed unmechanical to have a huge blowing-cylinder with a stroke of probably not more, and perhaps a good deal less, than a quarter of its diameter, and he looked forward to the day when designers would succeed in making slow-running gas-engines with long strokes. When they had succeeded in doing that they would have achieved a great advance, because they would have produced an engine which was applicable to very many purposes for which the gas-engine was not suited at the present time. The gas-engine had undergone great development, but before it could be used universally that development would have to be carried farther. The constant high speed necessary to the ordinary gas-engine of the present day was right enough for many purposes, such as generation of electrical power, lighting, etc.; but there was need of a gas-engine constructed on a principle which would admit of long strokes and few revolutions. He did not see any insurmountable difficulty in the way of that, and it was only necessary for engineers to take up the subject and thrash it out. He looked forward to the time when gas-engines would be made of universal application, and when that time arrived Sir Frederick Bramwell's prophecy would be fulfilled, that the steam-engine would disappear and the gas-engine would hold the field. Mr. Davey.

Mr. T. Canning observed that he believed the Author was pointing out the right way of utilizing blast-furnace gases which had gone to waste for so long. At the same time, he thought the Author had not made it quite clear how the gases were collected. With regard to the cooling and purification, he considered that in that process some of the most valuable constituents of the gas, the higher hydrocarbons, were lost. In South Wales an attempt had been made more than once to utilize the blast-furnace gases in the steel-melting furnaces. They had been carried over in steel pipes, but the loss upon the way had been very great, principally by condensation and in what was commonly called dust, which was also to a certain extent condensation. The heavier hydrocarbons, valuable heat-producing gases, were lost. He wished to know how much of the actual energy of the gases at the start was really made use of. He thought it could not be a very large portion. There was no doubt that the question was one of immense importance and one which would attract the attention of all who were interested in the manufacturing industries of Great Britain. A vast amount of power had been wasted year by Mr. Canning.

Mr. Canning. year, but he was not sure that the Author had shown exactly the best way of economizing that power.

Sir Frederick Bramwell. Sir FREDERICK BRAMWELL, Bart., Past-President, remarked that he could not follow his friend Mr. Davey in his desire for a long-stroke engine. He thought Mr. Davey had in mind waterworks engines with cataracts, which stood still for some seconds and then went off with a bang. When they did go they worked with great rapidity, but he did not see what good they did when they were standing still. Except for pumping—and he did not believe there would be an excess of that—rapidity of rotation was what was required for all purposes. An engine was not required which ran at 30 revolutions and needed to be geared up four times in order to work at 120 revolutions per minute. The engine should work at 120 revolutions per minute direct. Locomotives ran at more than 30 revolutions per minute, as did also screw-steamers. He did not know for what purpose slow-running engines were required at the present time, except for the single purpose of pumping; and even in regard to that he would call Mr. Davey's attention to the many engines now used for pumping purposes which were making a very respectable number of revolutions per minute and doing good duty. He did not see, therefore, why the gas-engine was not to be looked upon as perfect until it could be made to run slowly, and it seemed to him rather an odd requirement. He desired it to run quickly and to do useful work.

Mr. Beaumont. Mr. W. WORBY BEAUMONT, referring to the question of valves, remarked that valves for much higher speeds than those referred to, and running under very high temperatures, were now made successfully; although a few years ago it had been extremely difficult to get a valve that would stand for any length of time. Those acquainted with modern work in connection with small engines of very high speed and power would be able to satisfy Mr. Davey on that point. When power could be obtained for nothing, as might be said to be the case with blast-furnace gases, an engine might well be run at the speed necessary for gas-engines, even if a little of the gas were wasted in driving the blowing-engine through gearing. In the Author's reference to the calorific value of the gases, and his statement that it was owing to the small dilution with air and the high compression used that the thermal efficiency of blast-furnace gases in an engine-cylinder was so high, Mr. Beaumont did not quite see the sequence; but inasmuch as up to a certain point increasing the compression would increase not only the power given out but also the efficiency

of the gas-engine with a given mixture, he would like to know a little more as to what was the pressure at ignition or the highest pressure during combustion, and the nature of the continuation of the pressure throughout the working-stroke; in other words, some diagrams to support or confirm the generalization at which the Author had arrived. The Author also mentioned that compressions up to 11 atmospheres were employed. Inasmuch as that compression, other than as an experimental matter, was very high indeed, and as compression up to 7½ or 8 atmospheres seemed to be somewhat common for these engines, further information was desirable as to the maximum ignition-pressures and the nature of the diagram obtained from the engines which were giving high efficiencies with the characteristics of mixture and compression referred to. He also wished to know the nature of the apparatus by means of which the benzine vapour was supplied to a certain engine at Seraing as a means of starting it from rest by electric ignition. Mr. Beaumont.

The AUTHOR, in reply, agreed with Mr. Brown that the installation at Differdingen was very interesting. The gases there, which contained a large quantity of dust, were almost completely free from it after cooling, etc. They were purified from the light dust by the arrangement of fans in sequence driven by electric motors, and two fans were about to be fitted at Seraing on the same principle, the gas going first through one fan and then through the other. The results were remarkable. It had to be carefully borne in mind that the percentage of dust in the gases produced by various ironworks differed widely. There had never been a large quantity of dust at Seraing, but great trouble had been caused by it at Differdingen. The dust differed according to the ore used and to a variety of other circumstances. With regard to the remarks of Mr. Snelus, blast-furnace gas was of a low calorific value, being only about 100 B.Th.U. to 120 B.Th.U. per cubic foot. The calorific values of Dowson and Mond gases were slightly higher, that of Dowson gas being about 150 B.Th.U. per cubic foot. Coal-gas had a calorific value of about 600 B.Th.U. per cubic foot. It did not follow that as good an efficiency was not obtained with the gases of low calorific value in a good gas-engine as could be obtained with gases of higher calorific value. The valves in the blowing-cylinders, to which Mr. Davey had referred, made no noise, and worked at speeds even higher than those mentioned in the Paper. There were two or three different types of valves, and a system of Corliss valves. He quite agreed that they could be driven at much higher speeds. [Mr. DAVEY asked The Author.

The Author. whether some of the valves were not moved mechanically. He thought this had been found necessary.] Both systems were at work. As to the collection of the gases, there was always considerable air-pressure in the furnace, and that seemed to be sufficient to send them through all the coolers, fans, pipes, etc. It should be remembered that there were now engines aggregating about 100,000 HP. at work on the Continent with cooled and purified blast-furnace gases. In answer to Mr. Beaumont's question as to the pressure of explosion and the average pressures of the indicator-diagrams, large-scale indicator-diagrams would be found in Mr. Hubert's report referred to in the Paper, which was issued by the Société Cockerill.[1] With regard to the benzine vapour, he had seen the engine started, and he presumed the vapour was pumped into the cylinder, but he was not quite certain. Referring to a model of a single-acting blowing-engine cylinder exhibited by Mr. B. H. Thwaite, the Author remarked that on the Continent double-acting blowing-cylinders were preferred. He was extremely obliged to the members for the kind reception they had given to his Paper.

Correspondence.

Mr. Booth. Mr. W. H. Booth remarked that, to those engineers who were familiar with the history of the utilization of blast-furnace gas for motive-power purposes, the Paper savoured somewhat of the play of "Hamlet" with the Prince of Denmark left out; for there was very little recognition of the originator of the whole movement, the Englishman, Mr. B. H. Thwaite, and a great deal of the foreigner, who had only come in after Mr. Thwaite had made public his own researches. Some time in 1894 Mr. Thwaite had spoken to him on the subject, had noted the similarity between his producer-gas analyses and the analyses of many waste gases from blast-furnaces, had synthesized a gas to the blast-furnace quality, and had proved by actual trial that it would run faultlessly in a gas-engine. Hence had arisen the installation of the plant at Wishaw, which had run in its original form ever since, lighting the ironworks. He had made the first independent test of it in August 1896, and the Author was in error in stating

[1] In the publication referred to in the foot-note to p. 37.

that some difficulty had been found in starting. There had been no difficulty in starting, and no such words occurred in his report. On the day when the power-tests had been made, the gas coming off had been of very poor quality, but no analysis had been made. Mr. Galbraith, however, had made the three analyses mentioned in Mr. Booth's report, which had shown that the calorific value of the gas varied between 99 B.Th.U. and 117 B.Th.U. per cubic foot; and it was probable that the tests had been made with gas nearer the lower figure: certainly the gas had not had the calorific value of 126 B.Th.U. mentioned in the Paper, nor did he see how this figure could have been obtained from his report. It was quite an error to suppose that gas from a coal-fed furnace was richer than gas from a coke-fed furnace. In matters like this it was impossible to go behind the analysis, and analysis showed that the Wishaw furnaces gave poorer gas than the coke-fed furnaces of the Frodingham works. The gas coming off at Wishaw might be better, but he was referring, of course, to its condition as issued to the engine after it had had the ammonia and tar removed by the residuals plant. Much weight could not be given to the statement that Mr. Lürmann had recognised the value of blast-furnace gases in 1886; at least, that gentleman did not appear to have set much value on his own opinion, for in 1898 he had strongly opposed the idea of their utility as a source of motive power. The first person to recognise that blast-furnaces produced a useful gas had been, Mr. Booth believed, Neilson, of hot-blast fame, in 1828, the year in which the blast-furnace had been blown out in Sussex. Producer-gas had not even been used in gas-engines before the early eighties, and it was certain that the first recognition of blast-furnace gas for power-production had been that by Mr. Thwaite, which had been published soon after by him,[1] and had become known to the Belgians and to others. While no credit could be awarded to those who had endeavoured to deprive Mr. Thwaite of credit, he thought the reverse might be said of the iron-masters of the Continent who had recognised the merit of Mr. Thwaite's invention, while English iron-masters had practically ignored the economy to be received, despite the successful running of the initial Wishaw plant during the past 6 years. The question of dust was very important, and Mr. Thwaite had realized from the first the necessity of purifying and cooling the gases. The utility of this had been denied by the Belgian engineers, and the Author seemed to have become imbued with the same idea. The dust of Mr. Booth.

[1] *Iron and Coal Trades Review*, 16 November, 1894.

Mr. Booth furnace-gas consisted of lime, fine coke, and ore-dust. The heavier portions settled by gravity, but a final filtration was necessary if gas-engines were to run for any length of time without undue wear and friction. Cooling the gases, if well done, assisted to remove dust, and it was essential to cool the gas to deprive it of its moisture, for, as was well known, moisture in a gas-engine caused serious diminution of power. It was, he felt confident, bad practice to neglect cooling and filtration, especially as the gas could be cooled in the economizer type of cooler, thereby heating the air flowing to the furnace from the blast-engine. In this cooler, as proposed by Mr. Thwaite in his Paper read at the Engineering Conference at Glasgow in 1901, the cooling-tubes were kept clean by scrapers, which pushed down all dirt and dust, and at once drowned the lime, which otherwise would tend to set. In view of the full utilization of the waste gases Mr. Thwaite proposed to heat the blast-stoves by means of producer-gas, free from the lime dust which rendered the ordinary stoves so very inefficient, but this opened out too wide a field for further discussion. It might be added to the record of the Wishaw test that the consumption of gas included that necessary to drive the supply- and circulating-fan. The engine had then been doing considerably more work than was shown by the electrical instruments, the fan being looked on as part of the engine. This fan helped to purify the gas, its capacity being five times what was actually needed. It thus circulated the gas through the holder, and was therefore superior to the complications involved in the use of two or more fans in sequence. The neglect of obvious economies in this country was strikingly manifested at the new power-station of the Midland Power Distribution Co., at Ocker Hill, near Tipton. This large station, provided with steam-boilers to use coal, was in the midst of a district of blast-furnaces capable of supplying many similar power-plants. It was very difficult to make men believe that blast-furnace gas would burn in a gas-engine. The gas was of such a dilute nature that sometimes it would hardly burn under a boiler; therefore, it was argued, it could not be satisfactory in an engine. These objectors entirely overlooked the effect of molecular approximation which followed on compression of the gaseous charge. Such compression caused the poorest gas to ignite readily.

[Com]pagnie [Français]e des [Moteurs] à Gaz [et des C]on[struct]ions [Mécan]iques. The Compagnie Française des Moteurs à Gaz et des Constructions Mécaniques, of Paris, pointed out that a number of large gas-engines had been constructed on the Otto system by the Gasmotoren-Fabrik Deutz since those mentioned by the Author,

notably two 1,000-HP. engines for Dudelingen and Hörde, respectively. At the present time three engines of 1,000 HP. and others of 600 HP. and 500 HP. were under construction. Installations of Otto engines had been made for the generation of three-phase electric current, the engines running in parallel, as, for instance, at Dudelingen and Friedenshütte, where the variation of speed was $\frac{1}{150}$. The Compagnie Française des Moteurs à Gaz et des Constructions Mécaniques.

Mr. W. HAWDON, of Middlesbrough, remarked that, taking the Author's figures of 162,000 cubic feet of blast-furnace gas per ton of iron made (although in making Cleveland iron it was found to be about 156,000 cubic feet) and the surplus gas as being 37,000 cubic feet, which seemed to be approximately correct, there would be obtained with a furnace making 1,000 tons per week (or, say, 6 tons per hour)— Mr. Hawdon.

$$\frac{37,000 \times 6}{123} = 1,804 \text{ HP.-hours}$$

from the spare gas; and this when using a portion of the gas under boilers for driving the blowing-engines: and as the process was continuous, there would appear to be about 1,800 HP. to be obtained from a furnace making 1,000 tons of pig-iron per week.

Mr. E. KÖRTING, of Hanover, remarked that Messrs. Körting Brothers used compression up to 13 atmospheres with power-gas and 10 atmospheres with lighting-gas, owing to special arrangements in the combustion-chamber to reduce the high temperature of the compressed charge. Consequently the thermal efficiency reached 33 per cent. by brake horse-power and 38 per cent. by indicated horse-power, and they had been able to run two engines of 125 HP. at the Mansfelder Gewerkschaft with gas having a calorific value of only 629 kilogram-calories per cubic metre (71 B.Th.U. per cubic foot); they had offered lately engines for gas of only 520 calories per cubic metre (58 B.Th.U. per cubic foot), and were confident that these would prove successful. The new double-acting two-cycle Körting engines admitted of being forced in the following sense. The combustible charge of four-cycle engines was not greater than 80 per cent. of the volume displaced by the piston, whereas in the new engine, which was designed to run normally with a charge of also 80 per cent. of the volume displaced by the piston, they were enabled to increase the volume of the charge up to 115 per cent., which meant an increase of power of at least 50 per cent. on normal power. They constructed their engines with a gear to modify the time of ignition in reference to the dead-point position, and therefore they were able to run the engines as slowly as they pleased with the same good result, and, in fact, with the same Mr. Körting.

Mr. Körting. diagram, as if the engine were running at normal speed. There was no difference in this respect between a steam-engine and a gas-engine, if only the required steps were taken to change the time of ignition. If the combustion-chamber was properly constructed and provided with suitable means for reducing the temperature of the compressed charge, there was no danger of premature explosion, even with the largest cylinders.

Mr. Lürmann. Mr. FRITZ W. LÜRMANN remarked that he had drawn attention in 1886[1] to the advantages of the use of blast-furnace gases in gas-engines.

Prof. Meyer. Professor E. MEYER, of Charlottenburg, in regard to the relative advantages of single- and multiple-cylinder engines, agreed with the Author and Professor Witz that complete experiments with a large four-cylinder engine, comparable with those carried out under the direction of Mr. Hubert with the Société Cockerill's single engine of 600 HP. at Seraing, were much to be desired. In such trials, in addition to the determination of the indicated and electrical horse-power, the use of a reliable brake was essential in order to obtain data for the comparison of the mechanical efficiency of the two types, as on this important question information was entirely wanting, not only with gas-motors but also with steam-engines; that was, it was not known to what extent multiplication of the number of cylinders increased the frictional loss, and so neutralized in part the saving of steam per horse-power-hour. On the other hand, he considered that the question which class of engine might be most advantageously adopted could not be solved by such experiments, as that was not dependent upon the gas-consumption, which, according to his view, would be nearly the same in either case, supposing both engines to be equally well designed and constructed. The choice in such cases would be governed mainly by considerations based upon constructive details, price, degree of uniformity of speed, etc. For certain purposes the single-cylinder engine would probably be indicated, while for others, especially where a high degree of uniformity in running was necessary, the multiple-cylinder type would probably be preferred. It was therefore easily conceivable that both kinds might justify their combined existence side by side. In other words, the question of preference was to be decided rather from the results of experience gained in the drawing-office, the shops and in actual work, than from the most exact determinations of useful mechanical effect alone.

[1] Zeitschrift des Vereines deutscher Ingenieure, vol. xxx. p. 704.

Mr. MAX MÜNZEL, of Mülheim-on-Rhine, remarked, with reference to the statement that the advance of the gas-engine limit from 10 HP. to 1,000 HP. had occurred between the years 1895 and 1900, that, as far back as 1891, a twin engine of 120 HP. had been at work at the central electric-lighting station in Dessau, with cylinders 500 millimetres (19·7 inches) in diameter and 760 millimetres (30 inches) stroke, making 140 revolutions per minute. The fact that increase in cylinder-dimensions had been realised but slowly was to be attributed to the circumstance that, at that time, lighting-gas had been used; and, with this, difficulties had been encountered with the engine in question, owing to premature ignition and consequent sudden reduction in speed of the motor, which it had been possible to remedy only by cooling the outlet-valve by a water-injection in the exhaust-pipe. The valve, being placed on the side of the cylinder, could not be cooled by the incoming current of gas and air. That heating-gas of a lower calorific value gave less trouble in regard to this particular difficulty had only become generally known with the extension of the use of Dowson gas; previously there had been no reason for experimenting on larger cylinders, not merely on account of the increased risk, but also from the high price of the fuel, which it had only been possible to employ advantageously when the consumer had had his own gas-works, so as to obtain the fuel at the cost of production. With the recognition, however, of the fact that blast-furnace gas could be equally well used for direct generation of power, increase in the size of the engines had followed very rapidly, the most notable advance being that made by the Société Cockerill from 200 HP. to 600 HP. in a single cylinder. This class of engine, of which a considerable number had been made, had a cylinder 1,300 millimetres (51·2 inches) in diameter and 1,400 millimetres (55·1 inches) stroke, or a ratio of stroke to diameter of 1·08 : 1, which had not previously been used in gas-engine construction. According to the information which had reached him from Differdingen, this combination of large diameter with comparatively short piston-stroke had given rise to difficulty from leakage which could be met only by liberal use of the best viscous cylinder-oil. About a year ago, in conversation with the Author, he had expressed the opinion that 250 HP. in a single cylinder 850 millimetres (34 inches) in diameter, was the maximum advisable with blast-furnace gas. This view had been based upon the then existing want of experience of the working of large engines for prolonged periods, and the fact that the difficulty of keeping the piston tight was, as every builder of gas-engines knew, notably

Mr. Münzel. increased by increase of the cylinder-diameter. The principal reason, however, against the use of single-cylinder engines of large power was the necessity of using an excessively heavy fly-wheel, even when only a moderate degree of regularity in running was required. In a single-cylinder 600-HP. engine, with the ignition controlled by a hit-and-miss motion, it was even worse; as this method of governing, in conjunction with a low number of revolutions per minute, resulted in such irregular working as to be inadmissible for ordinary purposes, and sufficed at most for pumping- and blowing-engines. As it was not feasible to equalize such irregularity by the use of heavy fly-wheels, owing to the impossibility of bringing the necessary weight into the rim of the wheel, the above limit of 250 HP. was considered to be sufficient, as the requirements of the smelting-works were entirely for driving alternating-current dynamos with a maximum duty of 1,000 HP., but with such a degree of uniformity as could not be obtained by hit-and-miss governing. Even for a blowing-engine he considered it desirable that a variation of 50 per cent. in the number of revolutions should be attainable without prejudicing too greatly the uniformity of working, and therefore that a two-cylinder engine was best suited for such work. When the exhaust-valve was placed low down, which was undoubtedly advantageous for the expulsion of dust, there was a corresponding disadvantage in the tendency of the lubricating-material of the cylinder to follow the same path, so that the piston might run dry unless provision was made for continuous heavy lubrication. In order to secure the latter conditions it was therefore desirable that the exhaust-valve should be placed at a higher level, which further required that the gear should be as perfectly cleaned as possible to prevent the accumulation of dust in the cylinders and valve-boxes. In this respect the use of fan blowers with water-injection for gas-cleaning, first adopted in practice on a large scale at Dudelingen and at Differdingen, was a very important advance towards facilitating the direct use of blast-furnace gas in motors. At the Gutehoffnungshütte at Oberhausen, where there were at work six Otto gas-engines, collectively of 2,200 effective HP., this system of wet centrifugal cleansing had been subsequently introduced, with the result that the gas-mains which had formerly required cleaning at intervals of 14 days at most now ran for more than 6 weeks without calling for any special attention. With regard to governing, the best method of working was to keep to the full Otto cycle without cutting out ignition, the engine taking in air and gas in the same proportion at all loads,

Mr. Münzel.

but at a lower compression as the load diminished. Electric ignition, in his experience, gave excellent results at all loads, in respect of both gas-consumption and uniformity of running. For the starting of large engines compressed air was to be preferred to benzine vapour. If, as usually happened when the engine was cold, the valves and pistons were not quite tight, part of the inflammable mixture in the outer case would escape during the compression period on the return stroke of the piston, so that the charge might not be strong enough to start the engine with the impulse of one ignition, with the result of a sensible loss of time on the expulsion of the burnt gas, until the cylinder was ready for a new charge. With compressed air this difficulty was overcome, for if one impulse was not sufficient, the automatic compressed-air valve gave a second or third, and the motor in all cases started with the regularity of a steam-engine in a few minutes. There could be no doubt as to the number of cylinders to be used under present conditions. With alternating-current generators running in parallel in a central station, single cylinders were impossible except when the dynamo was belt-driven, which excluded their use for large power-units. The conditions were fairly satisfied with twin Otto-cycle motors, but more easily and perfectly with four-cylinder engines. Twin motors coupled in parallel were in use at the Friedenshütte works, and others with four cylinders at Dudelingen. When uniformity of working was not specially demanded, the single-cylinder engine might be preferred on the ground of greater simplicity in construction; but here it might be noted that the original outlay in working-cost was about the same for all classes, whether with one, two, three or four cylinders. An advantage of the single-cylinder engine was to be found in the smaller number and more ready accessibility of the moving parts requiring lubrication, giving lighter work for the engine-room attendant; but in this respect twin engines with cylinders side by side would be about on an equal footing for similar power. As it was now a well-established fact that a notable economy was obtainable in ironworks by the direct use of gas without the intermediate agency of steam-boilers, further elaborate experiments on gas-consumption seemed to be unnecessary. The consumption of a few cubic feet more or less per effective horse-power-hour was a matter of small consequence. More important, however, was the question of the suitability of the engine for the conditions of long-continued work called for in ironworks, and in this respect experience alone could decide as to the best form. As regarded economy of working and

Mr. Münzel. price, the different systems in use at the present day—the Otto, Oechelhaüser, Simplex and Körting systems—were substantially of equal value, and it was to be expected that the combined experience of smelter and engine-builder would result in the development of a type combining all the best points of the existing systems. As supplementing the information previously given, it might be stated that at Hörde, to the four Oechelhaüser 600-HP. engines, an Otto motor of 1,200 HP. had been added, and another of the same size was in course of erection. At the Höesch works in Dortmund two 300-HP. Otto engines were supplied directly from the blast-furnace gas-main without an intermediate gas-holder, which latter item he considered to be unnecessary when the gas-conduits were of sufficient length and diameter. The degree of compression to be adopted for gas in proportion to its calorific value was a matter of considerable importance, especially as regarded prevention of premature ignition. The compression-space should be as simple in shape as possible, and with a minimum ratio of surface to capacity, which pointed to the use of a form as nearly spherical as might be. With such an arrangement the necessary degree of compression to be used might, according to his experience, be found by the empirical formula

$$C = 5 + \frac{8{,}000}{H}$$

where C = compression in atmospheres (absolute),
H = minimum calorific value per cubic metre in kilogram-calories,[1] as determined by the Junkers calorimeter.

Taking H = 1,000 the above gave as the most advantageous degree of compression, C = 13 atmospheres absolute; or 12 atmospheres, or 170 lbs. per square inch, excess pressure. The recent development of the waste-heat power-engine, in which an auxiliary engine was driven by sulphur-dioxide vapour evaporated with the surplus heat of condenser-water, placed the large single-cylinder gas-engine in another light. If the heat of the exhaust gases and the jacket-water were to be applied to the evaporation of sulphur dioxide in the same way as had been done successfully by Professor Josse in Berlin with the steam-engine, a double-acting low-temperature vapour-engine could be attached to the crank-shaft of the gas-motor, with the result of considerably improving the regularity of rotation, and realising about 33 per cent. additional power; or

[1] If the calorific value be expressed in British thermal units per cubic foot, h, the formula becomes $C = 5 + \frac{903 \cdot 2}{h}$.

in other words, a 600-HP. engine would develop 800 HP. for the same gas-consumption, and the thermal utilization would be raised to between 35 per cent. and 40 per cent. by the combination. A further advantage in such a combination would be found in the diminished weight of fly-wheel required to attain uniformity, and it would therefore be admissible for driving central-station alternators. The question of whether single- or multiple-cylinder gas-engines should be used must decidedly be answered in favour of the former. The working of waste-heat engines, however, required a very large supply of cooling-water, amounting to 300 litres per horse-power for a difference of 10° C. between the temperatures of injection and discharge. The method advocated would therefore be possible only where condensing-water was readily obtainable. Further information on the subject was to be found in a pamphlet entitled, "Recent Experience and Tests with Waste-Heat Engines," by Professor E. Josse.[1] Mr. Münzel.

Mr. Pritchard.

Mr. P. M. PRITCHARD considered that somewhat undue prominence was given to the efficiency of gas-engines using blast-furnace gases, considered as heat-motors. Where, as in large ironworks, there was in the waste furnace-gases practically an unlimited supply of power to be drawn upon, the first consideration was to build an engine which would be entirely free from breakdowns, and which could be relied on to run continuously for any length of time. This was particularly true when the engine was utilized for meeting a continuous demand for any form of power, whether as electric energy or as the power required by a blowing-engine. The tests made by various authorities and cited by the Author were valuable as showing what might be done in the direction of economy, but they did not give any information as to the mechanical efficiency and reliability of the engines tested. Although it was not to be expected that the makers would supply working-drawings of any of the engines which they had built, for publication in the Proceedings, yet it would be of interest if the Author could put before the Institution a log of the running of some of these large engines over an extended time, giving full details of the running, and mentioning defects, if any, which had developed, with their cause and remedy. His attention had been attracted to this matter owing to the apparent reluctance of engineers responsible for the design of large power-stations to adopt gas as their motive power, a reluctance which was all the

[1] Mittheilungen aus dem Maschinen Laboratorium der Kgl. Techn. Hochschule zu Berlin. See also Minutes of Proceedings Inst. C.E., vol. cxlvii. p. 467.

Mr. Pritchard. more remarkable in view of recent developments in the methods of recovering by-products in gas-producing plant. Referring to the Seraing 600-HP. motor, the diameter of the shaft was given as 18 inches, with a cylinder-diameter of 4 feet 3 inches. This ratio contrasted strongly with the Westinghouse practice, which made the diameter of the shaft about one-half of that of the cylinder. There would appear to be considerable divergence in practice in this respect, and any information the Author could give as to standard practice would be acceptable. He had found that a shaft 10 inches in diameter was fully small for cylinders 20 inches in diameter using gas having a calorific value of 500 B.Th.U. per cubic foot.

Mr. Sauvage. Mr. E. Sauvage, of Paris, agreed entirely with the Author's statements. He believed there was little doubt that the use of blast-furnace gases in motors was attended with a real economy. Of course, for want of sufficiently prolonged practice, the cost of repairs could not as yet be computed with accuracy; it would be prudent to suppose that these expenses might be larger than for a plant consisting of boilers and steam-engines of equal power. It was hardly possible to say which was the best of the existing types of gas-engines for such work, principally the Otto, Simplex and Oechelhaüser. Probably but little practical difference would be found, the construction being carefully carried out in all cases: this condition appeared to be essential. The reason why the consumption of water was greater with large cylinders than with smaller ones, as stated at p. 19, was not obvious, and he wished the Author would give some explanation on this point. A few details of the fans with water-injection for purifying the gases would also be of interest.

Mr. Theisen. Mr. E. Theisen, of Baden-Baden, considered the cleansing of blast-furnace gas by the joint action of a centrifugal fan and water-injection to be incorrect in principle and wasteful of motive power. In his method a centrifugal drum washer was used, in which the gas entering at one end was forced into contact with a thin film of washing water on the inner surface of the drum, moving in a spiral path from the opposite end. In this way very large working-surface was developed; for instance, in a No. 5 machine, with a cylinder 9 feet in diameter and 11 feet in length, making 300 revolutions per minute, an effective washing-surface of 200,000 square feet per minute was obtained. In one instance, where the apparatus had been continuously in use for more than a year, gas taken warm from the main with 3·6 grams of dust per cubic metre (1·6 grain per cubic foot) and 36 grams of water-vapour per cubic metre was purified to 0·01 gram of dust

and 3 grams of water-vapour per cubic metre. In its latest improved form the apparatus had been applied in numerous instances on the Continent, and up to a maximum capacity of 1,400 cubic metres (49,000 cubic feet) per minute, as well as in England. It had also been applied to clean the chimney-gas from boiler-flues from dust, sulphur gases, soot, &c., with the additional advantage of giving an increased draught, whereby the evaporative capacity was increased by from 50 per cent. to 60 per cent. Apart from the direct use of the gas for power, there was great advantage in using it in a perfectly clean condition in blast-heating stoves, so as to do away with the stoppage for cleaning, whereby the stove plant might be reduced by two or three stoves per pair of furnaces, representing a saving in the cost of fuel of about £10,000. When compared with fans, the economy in motive power was considerable. Thus, in one large ironworks, where two fans, cleaning 210,000 cubic feet per hour and reducing the dust to 0·2 gram to 0·3 gram per cubic metre (0·09 to 0·13 grain per cubic foot), were in use, a motor of 110 HP. was employed. Recently the limit of dust had been reduced in the Theisen washer with 40 HP. to 0·004 gram per cubic metre (0·0017 grain per cubic foot). Such purity would not be obtained with fans, even if four fans and 160 HP. were employed. Mr. Theisen.

Mr. R. Hanbury Wainford, of Newcastle-on-Tyne, remarked that the subject was so exhaustively dealt with by the Author that there appeared to be but one question open to comment, viz., the separation of the dust, which was admittedly difficult to effect and somewhat expensive. Some account of his experience in this direction might be of interest. For many years before it had been found possible to use blast-furnace gases directly for motive power, finely-divided powders had been successfully separated from air travelling with high velocity in considerable volume. A tornado-like centrifugal action was induced, or large settling-chambers, into which dust-charged air was directed, were used; but one simple and compact method had given such satisfactory results that a brief description of it might be permitted. This was a rectangular box placed horizontally, and having several dividing partitions arranged internally, upon the sides of which were fixed projecting angles, causing the current to be directed from side to side, and in so flowing to strike against and to some extent whirl round the angles or baffling-plates, thus setting up an eddying action which rapidly precipitated the dust into a hopper or conveyor below. It had been found that the first series of baffling-plates collected the greater portion of the dust, Mr. Wainford.

Mr. Wainford. including practically all the heavy metallic particles; and, on sifting, the large proportion of impalpable dust also deposited was noticeable, tending to show that to separate in one operation was possible. The succeeding chambers had baffling-plates at varying angles and less frequently placed. The Author might remember conducting some coal-dust trials about 8 years ago, which had been carried out as indicated in Sheffield; possibly he had witnessed them, and no doubt he would agree that the results had been satisfactory. Many other materials of a lighter nature had been dealt with in like manner. The Author's observation that to prevent deposits of dust a gas-engine cylinder should be constructed without sharp internal angles or corners was founded on the same principle as the dust-separator mentioned above. It might be added that the velocity of the gases (29·5 feet per minute as a maximum) was not high, and therefore was favourable to this system. Some doubt had existed in his mind as to the necessity of cooling; the high degree of compression to which the gases were subjected had settled this point; and further, a reduction in volume was advisable. To meet these requirements with the box described, surface-cooling must be resorted to, it not being permissible to apply water direct for the purpose. The box offered ample surface which could be jacketed, and the water could be caused to circulate through hollow partitions. There were one or two objections to cooling by means of a spray as described in the Paper. It would be noted that care must be observed that too much water was not used, an excess of water causing the gases to lose in calorific-value, and as there were continual fluctuations both in quantity and temperature of the gases passing, it would appear to be almost impossible to arrive at a proper adjustment. There was also the objection of dust-water (smudge) to be urged against this system. In coal-washing operations, in order to recover the water in anything like a clean state for further use, settling-ponds of large area in duplicate or triplicate had to be used, and considerable cost attended the separation of dust. It might, therefore, be correct to assume that similar difficulties would be met with in the case under notice. The Author might be able to give some information upon the matter, and he was to be heartily congratulated on his Paper, as were also the pioneers in the development of a great system.

Mr. Wright. Mr. H. E. Wright, of Middlesbrough, remarked, in reference to the analyses of gases given in the Paper, that they all showed an excessive percentage of carbon monoxide compared with Cleveland practice, and also hydrogen was in some cases in excess of that

obtained from Cleveland furnaces. A normal gas from these would contain about 10·5 per cent. of CO_2, 27·5 per cent. of CO and 0·75 to 1·25 per cent. of hydrogen. The gases described in the Paper showed an increased coke-consumption, and the power they would develop was greater than would be the case with the gas from a furnace worked economically in regard to fuel. The gas produced by furnaces using east-coast hematite was still poorer in combustible matter, the average amount of CO being found to be about 24 or 25 per cent., and these gases were saturated with water-vapour to the extent of about 10 per cent. of their volume. In consequence, it was found that the mean calorific value of the gas was lower than that stated in the Paper, and the normal figures for Cleveland gas or gas from east-coast hematite would be, Cleveland, 88 B.Th.U. to 105 B.Th.U., hematite, 78 B.Th.U. to 91 B.Th.U., without taking into account latent heat, etc. Owing to using less coke, experience in the works of Messrs. Sir B. Samuelson & Co. showed a less production of gas per ton of iron, normal figures for gas (dry at 0° C. and 760 millimetres pressure) being, Cleveland, 156,000 cubic feet, hematite, 147,000 cubic feet. The average quantity of dust stated in the Paper agreed in the main with his experience, viz., Cleveland, 1·35 grain per cubic foot (3·1 grams per cubic metre); hematite, 1·19 grain per cubic foot (2·7 grams per cubic metre). One-fourth of this dust was deposited in dust-catchers, one-half in the underground flues, and one-fourth passed to the boilers and stoves. The dust was not "metallic" at any stage; it consisted of fine burden, that was, fine mine-, lime- and limestone-dust, coke-dust and coke-ash. The following analyses showed the chief constituents of dust collected from furnaces smelting Cleveland ore:— Mr. Wright.

—	Insoluble Matter.	Alumina.	Lime.	Iron as Oxide.	Zinc Oxide.	Potash and Soda.	Loss on Calcination (Carbon & CO_2).
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.		
From dust-catchers .	18·2	10·0	8·9	20·1	12·0	..	18·5
From flues . . .	20·2	12·15	7·2	19·9	3·8	..	24·5
From stoves and boilers after combustion	14·3	10·00	12·0	5·95	10·44	13·44	23·55

[The absence of a reply to the foregoing Correspondence is explained in the foot-note at p. 1.—Sec. Inst. C.E.]

14 January, 1902.

CHARLES HAWKSLEY, President,
in the Chair.

It was announced that the Associate Members hereunder mentioned had been transferred to the class of

Members.

Parker Roscoe Allen.
John Benjamin Body.
William Cameron Borrowman.
James Forrest Brunton.
William John Clarke.
Norman Bonnington Dickson.
George Griffin Eady.
James Forgie.
Harry Francis.
Webster Boyle Gordon.
Percy Griffith.
Archibald Potter Head.
Dawson Kitchingman.
Robert Fletcher Leslie.
Alan Arthur Grenville Malet.
Horace Richard Marwood.
Thomas Walter Warren Melhuish.
Henry Hulbert Metcalfe.
Outram Faithfull Monier-Williams.
Marjoribanks Keppel North.
Charles Deane Oliver, B.A.I. (*Dubl.*)
Frank Oswell.
Thomas Raynes.
Bernard William Ritso.
Herman Alfred Roechling.
Arthur Hindhaugh Shield.
Cecil Archibald Smith.
William Oswald Taylor.
Alexander Pelham Trotter, B.A. (*Cantab.*)
Henry Titus Wakelam.
John Ward.
Arthur Lewis Webb, F.C.H.
Ralph Henry Wyrill.

And that the following Candidates had been admitted as

Students.

Kenneth Edmonstone Aitken.
Francis Cass Appleton.
Ronald Bugler Aries.
Henry Hawksley Ayris.
Jules Edmond Barbier.
Alfred John Best.
Frank Dixon.
Stafford William Down.
Arthur Stanton Ellerton.
George Herbert Fowler, B.A. (*Oxon.*)
Arthur John Grinling.
David Paton Grubb, B.Sc. (*Edin.*)
William Hawthorne, B.A. (*Royal.*)
Geoffrey Charles Hollis.
Robinson Friedrich Kesting.
Cecil George Charles King.
Herbert Kenneth de Kretzer.
Hadyn Lee.

Students—continued.

Kenneth Thurston Lomas.
Arthur Lees Mellor.
Richard Edward Michael.
Christopher John Mileham.
Charles Noel Moberly.
George Douglas Myers.
Harold Osmond.
Edward Davy Pain, B.A. (*Cantab.*)
Francis Tucker Patterson.
Harold Pool.
Cyril Humphrey Roberts.
Charles Francis Satow.
Reuben Marchant Sayers.
Leonard Ernest Silcox.
Gavin Trotman Brodie Smith.
Arthur Wetherall.
Francis Hugo Lindley Wood.
Cyril Roe Muston Young.

The Candidates balloted for and duly elected were: as

Members.

William Murray Alston.
William Hastings Cavendish, B.Sc. (*Victoria.*)
William Granger.
Christopher Wilhelm Hök.
Howard George Kelley.
John Morison.
Charles Cameron Nairn.
John George Robinson.
William Robert Shaw, M.E. (*Royal.*)

Associate Members.

Leonard Shelford Bidwell, B.A. (*Cantab.*), Stud. Inst. C.E.
Edward Seymour Skinner Boyle, Stud. Inst. C.E.
William Lowe Brown, M.Sc. (*Victoria*), Stud. Inst. C.E.
William Lyon Browne, jun., Stud. Inst. C.E.
Edmund Bruce Willoughby Cartwright, M.A. (*Cantab.*)
Walter Clapham, Stud. Inst. C.E.
William Collins.
James Conacher, Stud. Inst. C.E.
Alexander George Gordon Cumming, B.Sc. (*Edin.*)
William Stewart Hobart Dorman, B.E. (*Royal.*)
Cecil Arthur Fowler, B.A.I. (*Dubl.*), Stud. Inst. C.E.
Robert Halley Garvie.
Herbert Edward Terrick Haultain.
Maurice Walter Henty, Stud. Inst. C.E.
Daniel Jaffe, Stud. Inst. C.E.
Andrew Martin Ker, B.Sc. (*Victoria.*)
Cecil Lightfoot.
Arthur Burrow Linscott, Stud. Inst. C.E.
Edward Slater McDonald, Stud. Inst. C.E.
George Pascoe Mair, Stud. Inst. C.E.
John Scott Marshall, Stud. Inst C.E.
Charles James Kindersley Maurice.
Henry Eoghan O'Brien, B.Sc. (*Victoria*), Stud. Inst. C.E.
Albert Periam Pyne, Stud. Inst. C.E.
Edwin Hartree Rayner, B.A. (*Cantab.*)
Samuel Romilly Roget, M.A. (*Cantab.*)
Christer Peter Sandberg, jun., Stud. Inst. C.E.
Cedric George Vaughan, M.A. (*Cantab.*)
George Frederick Vollmer, M.Sc. (*Victoria.*)
Arthur Wingate Wingate-Saul, Stud. Inst. C.E.
Julian Stanton Wise, Stud. Inst. C.E.

Associates.

Frederick Nolan Baker, *Lieut.* R.A.
Joseph Gordon Gordon.
James Stirling.

(*Paper No. 3318.*)

"American Workshop Methods in Steel Construction."

By Henry Bridges Molesworth, M. Inst. C.E.

In view of the recent contracts for structural steelwork which have been let to American manufacturers at prices lower than those tendered by English firms, and the comment which these contracts have provoked, it appears to the Author that a description of American workshop practice in the manufacture of bridge- and girder-work might lead to a discussion of the reasons which render it possible for American firms to underbid English manufacturers in what should be their own market; and also to a consideration of the question whether some of the methods of manufacturers on the other side of the Atlantic might not be imitated here to the advantage of English manufacturers.

First, the idea that American bridgework is necessarily of the "cheap and nasty" class must be put on one side altogether. The Author's experience of first-class American bridgework is that it is fully equal, if not superior, to the best English work, in design, material, workmanship and finish.

The fact must be taken into consideration, however, that many tenders by American firms have been made at prices lower than those which they were obtaining for work in the United States; although against this it may be stated that many English firms also will tender for foreign work at lower prices than for home work.

The prohibitive duties on imports into the United States may have some bearing on the question of cost, as well as the British policy of free trade; but these are points which, although they influence prices, are outside the scope of this Paper.

The cost of labour is greater in the United States than in England; but the output of the individual labourer, and the hours which he may work, are not limited by the labour-organizations to the same degree as in England. For example, in America one man will handle a plate, say 10 feet by 6 feet by $\frac{5}{8}$ inch, under a punch, working entirely without assistance; in England he would have two to four men round him; and the American will get the holes punched in his plate just as quickly and as accurately as will the three to five men in England.

As a rule, bridge-works in England seem to have grown from small beginnings: an extra punch is added here, another there; the new tools are put in, probably after much consideration, where they least disturb or interfere with older machines; obsolete machinery is left alongside new machinery, and is not discarded because it can still do something; the ground becomes too small for the increasing machinery; the motive power is overtaxed; different departments encroach on each other; and there is a reluctance to make a clean sweep of the old machinery, and to lay out the works afresh. Works in America grow, but they seem to grow in a different way. Even comparatively new machinery, if superseded by anything better, is ruthlessly relegated to the scrap-heap. Frequently an entire plant is taken up, and new and improved machinery is substituted; and even when this necessitates a complete rearrangement of the works, there is no hesitation in carrying it out. A prominent American bridge-builder said to the Author: "When your works are full, you decline to take more work; when ours are full, and orders are still coming in, we enlarge;" and this principle appears to dominate American practice.

Works usually run night and day, the day shift in one week taking the night shift in the next. The impression received from watching workmen is, that the American never asks for assistance unless it is impossible for him to manage without it. The English workman appears hardly ever to do a job by himself, if he can possibly get any one to help him. Holidays are not so numerous in the United States as in England, and wakes and similar stoppages of work are unknown.

Having recently spent about 3 months at the Pencoyd Works of the American Bridge Company, near Philadelphia, and having previously had some years' experience as manager of bridge-building works in England, the Author purposes to give a general description of the methods by which American manufacturers turn out excellent work at a price which enables them to compete successfully with any English manufacturer. The Pencoyd Ironworks are on the right bank of the Schuylkill River, and are bounded on one side by the river, and on the other by the Philadelphia and Reading Railroad (Fig. 1, Plate 1). The river, though to some extent navigable by barges, is not used by the works. All their communication is by the railway.

Arrangement of the Works.—The works comprise open-hearth furnaces and rolls for all sections, but not for plates; also a

bridge-building department, to which the present description will be confined.

The areas covered by the various branches of the bridge-building department are as follows:—

Material-yard	150 feet by 240 feet.
Bridge-shop	450 „ „ 200 „
Loading-yard	120 „ „ 250 „
Eye-bar shop	230 „ „ 120 „
Forge department	180 „ „ 50 „

There is also a large drawing-office, occupying two floors in a large building, and a machine-shop for repairs and experimental work, where some of the machinery is made. A restaurant for the employees, and the general offices of the Company, are on the other side of the river.

The material-yard is the stacking-ground for all material delivered to the bridge-department from the Company's rolling-mills; it is served by lines of rails running parallel to the river, and by two electric cranes which run transversely to the river. All sectional material is received and sorted in this yard; plates are delivered by railway at the end of the yard, where there is a set of mangle-rolls for flattening them when received.

The bridge-shop is a covered building with glazed roof and sides and boarded floor; and is served by three longitudinal lines running the whole length, and by several shorter lines all running parallel and longitudinally. The cranes all run transversely, and are driven electrically. They transfer material from the skids to the trolleys and vice versa, and also transfer trolleys, with or without their loads, from one line to another. All material travels longitudinally on the lines, and transversely on the electric winches. There are also numerous electric pulley-blocks on overhead rails, and a few differential blocks where required. The cranes at the material-yard end of the bridge-shop are electrical winches with single lifting-chains; but at the loading-yard end they are girder hoists with two to four chains, which lift together, so as to handle long pieces without bending them. The steel from the material-yard is run into the bridge-shop on trolleys, and moved on to the skids, where any marking that is required is done; it is then taken to the shearing- or punching-machines; from there it goes in turn to the assembling-skids, to the gantry-drills, to the riveters, and lastly to the rotary planers, chord-drills, etc.; and finally it is taken out at the other end of the shop to the loading-yard, where it is painted and shipped. Every process

moves it farther along the shop, until the finished work emerges at the end opposite to that at which it entered as material.

The loading-yard is too small for the requirements of the works; and this at present limits their output, which might otherwise be larger. The yard is served by two 30-ton steam-cranes, which load up finished work on two sidings.

The eye-bar shop is devoted almost entirely to making eye-bars, for which the material is brought from the mills by a separate line outside the bridge-shop. The upsetting-machines, however, can be used for upsetting any bar. There is a testing-machine for testing to destruction eye-bars of any section and length.

The forge contains several steam-hammers, and the bolt- and rivet-making machines, screwing-machines, etc. All forgings are made here, and the material is brought by a continuation of the line which serves the eye-bar shop. All tempering is done in a special shop.

The output of the bridge-shop in 1895 was 39,635 tons, and this has increased steadily to 63,495 tons in 1900, and 36,906 tons up to the 30th June, 1901; or, in round numbers, from 3,305 tons per month in 1895 to 6,151 tons per month in 1901; and this with 375 men employed in 1895 and 667 men in 1901. These figures do not include draughtsmen, who numbered 41 in 1895 and 98 in 1901. The Table shows the amount of work done per

BRIDGE DEPARTMENT OF THE PENCOYD WORKS.

Statement showing the output per man per annum in tons of 2,240 lbs.

Year.	Draughtsmen.	Templaters.	Bridge-shop.	Forge.	Eye-bar shop.
1895	967	2,203	108	35	158
1896	871	1,960	109	43	141
1897	695	2,220	134	38	208
1898	728	2,596	114	45	161
1899	665	2,598	120	42	210
1900	721	2,442	107	51	227
1901	753	2,545	114	59	190
Average	771	2,366	115	45	185

NOTE.—The output per draughtsman and per templater is arrived at by dividing the total output of the works by the number of men employed. The output of the men employed in the bridge-shop, forge, and eye-bar shop, is arrived at by dividing the output of each department by the number of men employed in that department.

man per annum; and a comparison of these figures with those that any bridge-yard in this country can show will at once explain the low prices at which American bridge-works have been tendering.

Material.—The material is usually open-hearth steel. The American practice is to classify structural steel under three heads:—

Class of Steel.	Ultimate Strength. Lbs. per Square Inch.	Elastic Limit.	Elongation on a length of 8 inches.	Bending Test.
			Per Cent.	
"Rivet" . .	48,000 to 58,000	Not less than half ultimate strength	26	Flat on itself without external fracture.
"Soft" . .	52,000 „ 62,000		25	
"Medium" .	60,000 „ 70,000		22	180° to radius = thickness.

The Author found that nearly all the steel he tested was somewhat softer than that usually employed in England; the results of the tests were remarkably uniform, and the general quality of the steel was excellent, the only instance of rejection by him being one in which an ingot of "soft" steel had been rolled by mistake for one of "medium" steel.

All sectional material is straightened as soon as it is sufficiently cool. Angle-bars are run through mangle-rolls; joists and tee-bars are straightened in presses; plates are passed through mangle-rolls before they cool.

Drawing-Office.—The drawings are prepared in a very complete manner. Each sheet, in addition to the drawing, has a table showing the number required, the lettering and marking, the sizes and quantities of all material needed and the place where the finished piece is to go. The drawings for a large bridge comprise, in addition to the actual working-drawings, outline drawings with the stresses fully indicated on them, and also stress-diagrams.

Workshop Practice.—In the drawing-office every piece is scheduled; and the result of the practice referred to is that, if several hundred pieces of one pattern are required, they will all be made at once, will be precisely similar, and, when made, will at once be marked, so that there is no difficulty in assembling them. As an instance, the production of an angle-cleat with unequal sides—three holes on one side and four on the other—may be described in detail. The bars are carefully straightened and

brought to the angle-shearing machine, which has a stop fitted to the exact length of the cleat; the bars are sheared off into exact lengths against the stop; these short lengths are taken to a multiple punch having punches set on one side of the head for the three holes in one leg of the angle, and on the other side of the head for the four holes in the other leg. One puncher takes one of the angles with his right hand, passes it into the guides which must fit it, and thus three holes are punched; he withdraws it with his left hand, passes it through the gap of the punching-machine to a second puncher, who inserts it in the other side of the head, where the four holes are punched in the other leg. At each stroke of the punch one cleat is finished. The second puncher withdraws the finished cleat with his left hand, and it is at once marked by a third man and stacked on a trolley, which, when full, is taken away to be assembled. This procedure compares favourably with the usual practice in England, where each piece is marked off with a centre punch from a wooden template, is frequently sawn to exact dimensions with a cold saw, and is finally punched, each hole separately, by a single punch, with an accuracy which depends entirely on the skill of the puncher.

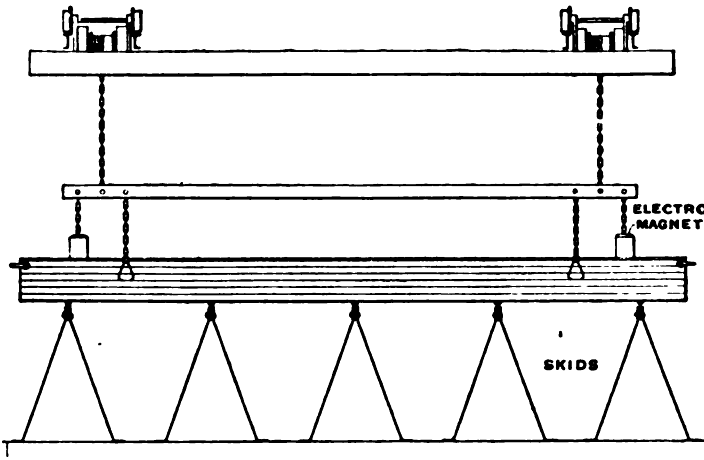
In joists the punching of the web is done by multiple punches, which have a separate stop to each punch; the joists are not marked but are run through the punch, which is of the close-mouthed type, and are pushed against a stop which runs on a graduated slide having a screw-clamp to fix it at any point. The man in charge of the stop has the drawing of the finished joist on the stop, which he adjusts accordingly. The holes in the flanges of the joists are put in by supplementary punches at the side of the main beam-punching machine. When punched, the joist is run straight forward to the coping-machine, and finished at the ends; then marked and sent forward to the assembling-skids.

Longitudinal or "main" angle-bars are punched on a spacing-table in pairs. The spacing is done by two levers, one working to inches and the other to sixteenths of an inch; and it is altered without stopping the machine. The spacer works with a sketch of the angle-bar before him. The accuracy of the back gauge is ensured by a self-acting finger on each side, which closes the backs of the angle-bars against each other before each stroke of the punches. The angle-bars are punched in pairs, and the flanges are punched in the same way on the same machine.

The angle-bars are placed ready for the machine on skids, and

are taken off by a long electric crane with clip-hooks and electro-magnets, as indicated by the diagrams (*Figs.* 2 and 2*a*). The clip-

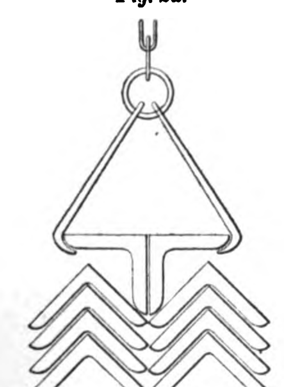
Fig. 2.



HANDLING ANGLE-BARS.

hooks lift the angle-bars until the backs are vertical, and then the magnets are lowered on to the upper flats and deposit the angles in place; after they are punched the table is run back by a quick-return motion and the punched-bars are replaced by another pair.

Fig. 2*a*.



CLIP-HOOKS.

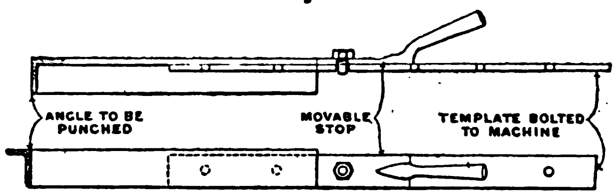
The Author has seen work turned out by the spacing-punch, and has inspected it when assembled for rimering. The accuracy of the holes left nothing to be desired, and was much greater than can be attained in the usual way. There did not seem to be any perceptible gain in a long length; 40-foot and 20-foot plate-girders were turned out literally by the hundred, and were assembled, the main angle-bars taken indiscriminately from one pile and the flanges and webs from another, with not a bad hole among them.

Small girder-webs (up to about 40-foot span), if not too wide, can also be punched in the spacing-punch, which will take in about 70 feet in length by 3 feet in width. In webs the

stiffener and web-joint holes can be put in at the same time as the main-angle holes, each punch having a separate stop.

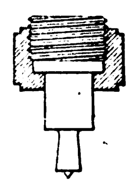
Small plate-girders are usually built without any camber, which greatly facilitates the use of automatic machinery. For punching stiffeners or other angle-bars where several are required alike, a flat bar is marked, punched with holes with the same spacing, and bolted down on bearers in line with the punch; a

Fig. 3.



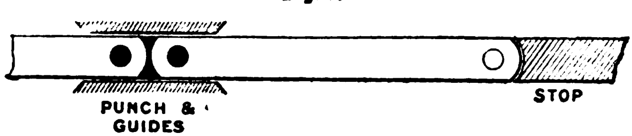
stop is held in the first hole, and the angle-bar to be punched is moved against the stop, which is changed from hole to hole in the pattern bar until all the holes in the bar are punched (*Fig. 3*). The back gauge of the angle-bar is accurately kept by a self-acting finger pressing the bar against the die holder, which is shaped to form a guide. In these punches it is the practice to have the stop which actuates the punch made so that, as each hole is punched, the stop springs out of gear; and in order to punch a hole the stop has to be moved into gear for each hole.

Fig. 4.



All punches and dies are made on an automatic, self-acting lathe, and are interchangeable (*Fig. 4*). Multiple punches are largely used. The punches, dies, and shear-blades are all kept in perfect order, and consequently the work is extremely good. Lattice-bars are turned out in a

Fig. 5.



punching-machine fitted with a punch and die of the form shown in *Fig. 5*. The bar is simply fed through the punch against the stop, and bar after bar is converted into absolutely accurate interchangeable lattice-bars without a possibility of

error. An appliance at every punching-machine for adjusting the work is a bar with a chisel-edge let into it, shown in the

Fig. 6.

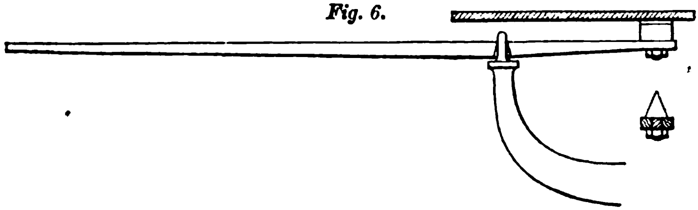
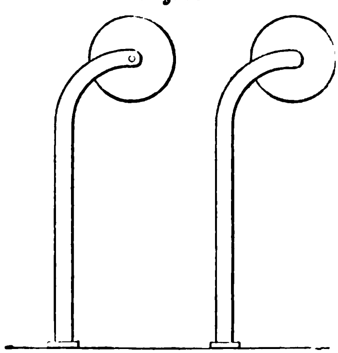


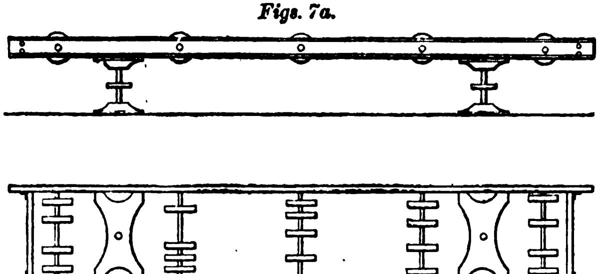
diagram (*Fig. 6*). The bar works on a pin which acts as a fulcrum and is attached to the punching-machine. Where an angle-bar or a tee-bar has to be moved forward, its use is obvious; but a plate can be moved in any direction by altering its position, and when it is used in conjunction with goose-necks (*Fig. 7*) and rollers, a plate of any size can be handled by one man. A large plate, when being punched, rests either on goose-necks at the same level as the die, or on a frame carrying rollers which are free to slide on their axles as well as to revolve (*Figs. 7a*). These frames are adjustable for height, and can be moved to any position required. The English method of sitting down and moving the work on the puncher's knees is never used.

Fig. 7.



GOOSE-NECKS.

Figs. 7a.



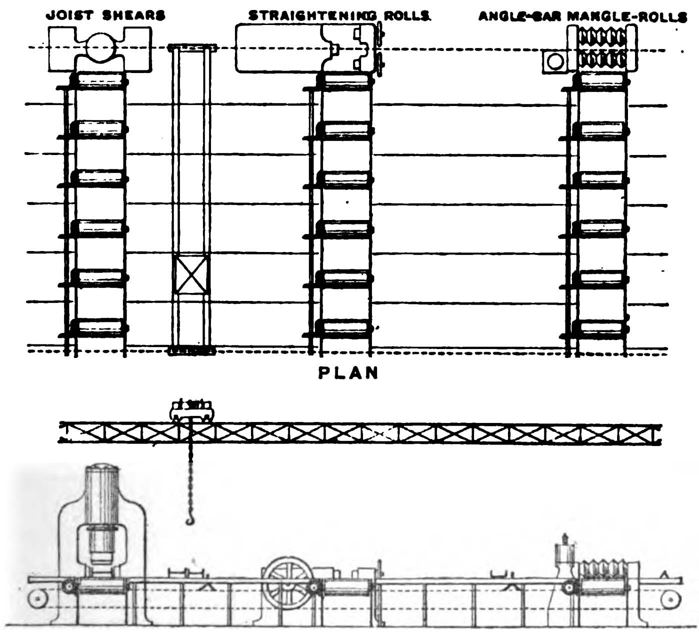
ROLLERS FOR MANIPULATING LARGE PLATES UNDER PUNCHING-MACHINE.

Swing-cranes on punching- and shearing-machines are not used, the work being supported on rollers or goose-necks.

Nearly all the larger shearing-, coping- and angle-bar cutting-

machines are mounted on turn-tables and are driven electrically; the motor is usually above the machine, and the connecting wires offer no obstacle to the movement of the machine on its turn-table. The machines are provided with sectors and stops to shear at any angle. The blades are kept in perfect order and adjustment; and, except by examining the cut surface, it is impossible to tell the difference between a cut made by one of these machines and a cut made by a cold saw. There is absolutely no distortion, and the cut is perfectly square and sharp. Angle-shears and coping-machines

Figs. 8.

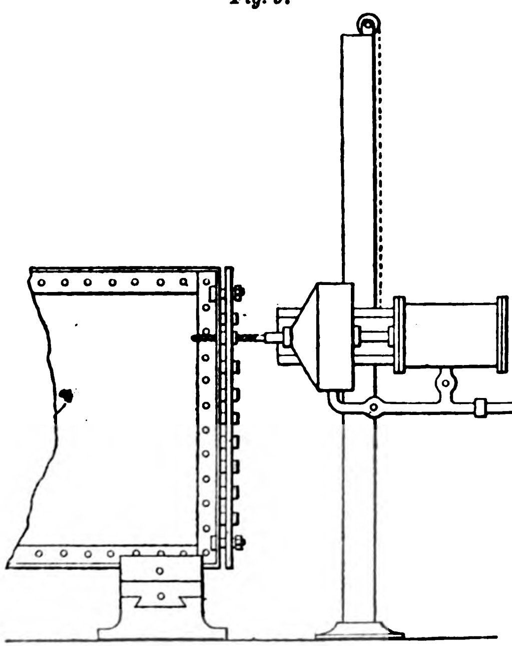


LIVE ROLLERS IN STRAIGHTENING-YARD.

have both right-handed and left-handed blades, so as to shear to a bevel on either leg of an angle-bar, or flange of a joist or tee-bar; and they are all provided with adjustable stops to shear to dead lengths. Joists of the largest size are sheared without the slightest distortion. The shearing-machines for joists are served —as is the straightening-yard generally—by overhead cranes and by lines of live rollers with skids between them. Any material is moved on the skids by mechanical traversing spurs driven by power, as indicated by the diagram (*Figs. 8*). This is a portion

of the rolling-mill plant. When work is assembled for riveting, even where rimering is not specified, it is usually taken under the rimering "gantry" drills, and a rimer is run through each hole. Drifting is little used, except to bring the pieces together. Should there be a bad hole at the riveter, a Boyer drill is run through in preference to drifting it; but this is rarely required. The "gantry" drills resemble a Wellington crane with eight radial drills mounted on it. The whole is driven and traversed electrically, the work being laid out on skids and the drills

Fig. 9.



DRILLING END TO TEMPLATE.

travelling from end to end of it. Pneumatic drills are largely used, and small pieces are taken under radial drills. Countersinking is done by the gantry drills when required on large pieces, and by radial drills on small, easily-handled pieces.

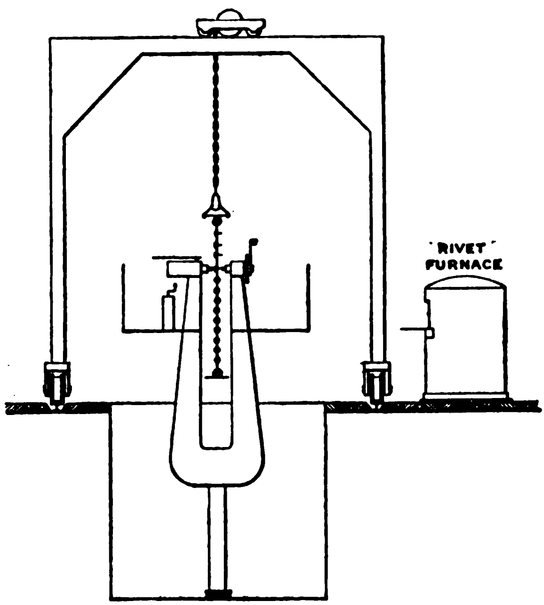
Pin-holes are punched out roughly in the material before assembling, and are bored out to exact size and position in the chord-boring machines, which are horizontal boring-machines adjustable on a long bed. The two holes, one at each end of a strut, are bored simultaneously; and in a boom or "chord" of a girder three or more holes are bored simultaneously. As

the boring-bars are exactly parallel to the surface of the bed, and at right angles to its length, the holes are necessarily accurate.

Girder-ends are drilled to templates by a Boyer compressed-air drill, travelling on an upright pillar on a rack, and counter-balanced; the feed being given by a small compressed-air cylinder behind the drill. The end of the piece to be drilled is held in a vice with a cross-traverse slide (*Fig. 9*).

Large plate-girders are riveted by a hydraulic riveter, which is mounted on a ram so that it can either sink below the floor or rise

Fig. 10.

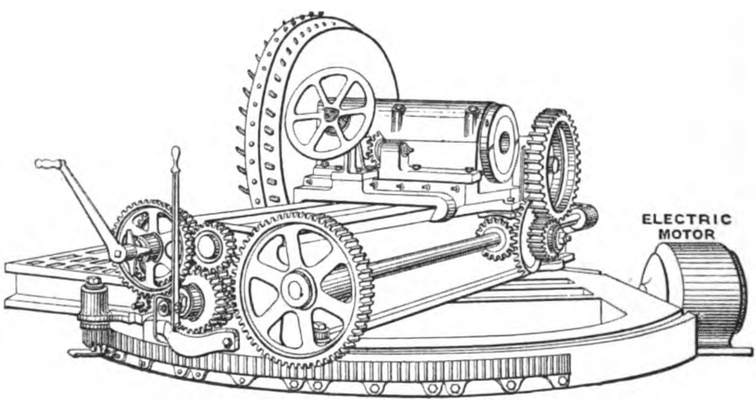


RIVETING LARGE GIRDERS.

above it (*Fig. 10*). The men actuating the riveter stand on platforms which rise and fall with it; and the switch which actuates the travel of the Wellington crane carrying the girder is on the platform. The back die of the riveter is fitted on a large quick-pitched screw with a hand-wheel and stop, and can be rapidly drawn back to clear stiffeners, or quickly adjusted to different thicknesses. The man working the riveter has two levers, one to raise or lower the machine, the other to close the rivet; a second man on the same platform works the switch which moves the crane and the girder forward. On the opposite platform

there are two men; one inserts the rivets, and the other works the screw which adjusts the die. The rivets are supplied from oil-furnaces, two to each machine. Small work is usually riveted on ordinary fixed hydraulic machines, and several pneumatic machines are also in use. Rivets are hardly ever put in by hand in the shop; any rivets that cannot be got in by the machines are put in by Boyer percussion riveters. The Author is of opinion that these pneumatic percussion riveters, when used by men accustomed to them, will close a rivet and expand the shank so as to fill the hole perfectly; but, like all other tools, in the hands of men not used to them they will do bad work. Countersunk rivets are dressed off flush by compressed-air chipping-machines, and any other dressing-off that is required is done in the same way. Nearly

Fig. 11



ROTARY PLANING-MACHINE.

all the material when in the bridge-shop rests on skids, and very little of it is allowed on the floor. There is comparatively little planing done in the works, owing to the extensive use of "universal" plates. Nearly all American plate-mills roll these plates, not merely to even inches, but to any width specified up to 48 inches; and these plates are used whenever possible. Makers will roll even a single plate to any specified width within their limits, without extra charge.

Where the ends of members are to be in contact, they are usually milled in "rotary planers," some of which are single and some double. The single machines consist of a bed-plate which can be turned horizontally at any angle, and which carries on a cross slide a large revolving planer-head, between 4 feet 6 inches and 6 feet in diameter, having a circle of cutters fixed in it near its

periphery. The head has a short hand-feed, which is adjusted to give a cut varying between $\frac{1}{16}$ inch and about $\frac{1}{2}$ inch; and a self-acting traverse motion, across the end of the member, planes it off to a true surface at any required angle, the depth of cut being dependent on the stiffness of the work which is being planed. *Fig. 11* shows a diagrammatic sketch of one of these machines. The double planers have one planer-head as described above, and a second which can be adjusted and fixed at any distance from the first on a rack-and-rail bed. Each planer-head is adjustable for angle, and is driven by its own electromotor. These rotary planers are used on all kinds of work, even to the finishing of girder-ends.

Angle-stiffeners are bevelled at the ends, to fit the roots of main angles, by a milling-machine with quick vertical feed, and are milled in pairs; as the cutter is the exact shape of the roots of the main angles, the fit is perfect. The accurate fit of the stiffeners is remarkable. The angle-smith is almost unknown, and smiths' work is kept out of the drawings as much as possible.

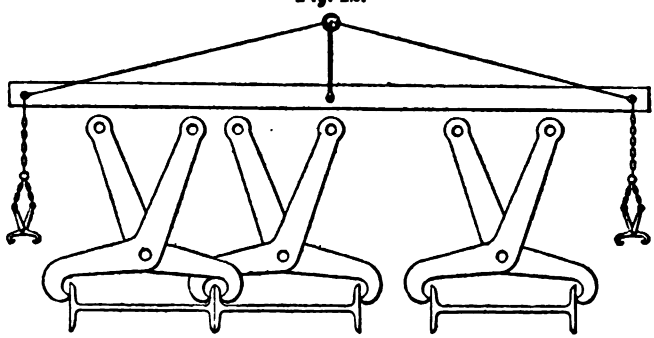
Eye-bars.—The pin-connection is still largely used in the United States; but the machinery for making eye-bars and pin-connections is so much used for other work, that it is as well to notice it here. Upsetting-machines, such as are used for the large sizes of eye-bars, would be of little use in England; but a machine capable of upsetting an ordinary bar, say 3 inches square, would be a most useful adjunct to any shop. The chord-boring machines too, which are necessary in American practice, would not be of much use in this country, where pin-connections are so little used. The usual specification for steelwork provides for the holes being punched $\frac{1}{8}$ inch smaller diameter, and rimered to $\frac{1}{16}$ inch larger diameter than the rivet, and the works are laid out principally for this class of work.

In the Pencoyd works, with the exception of the hydraulic and compressed-air machines, the whole of the bridge-shop machinery is driven by electricity. Some of the smaller machinery is driven by belt from shafting which is driven by electric motors; but each of the larger machines has its independent motor. Many of the hydraulic machines, such as the shearing-machines for large joists, have auxiliary electric motors for moving minor parts of the machines. The current is generated in a power-house with large dynamos, driven by condensing Corliss engines. The boilers are of the Babcock-Wilcox type, and are served by mechanical stokers. All the steam and the electric current for both power and light are supplied to the rolling-mills and furnace-plant from these boilers and engines. The steam for the air-compressors and hydraulic

pumps, which are close to the eye-bar shop, is generated in an independent battery of boilers.

For handling large joists or channels by crane, clip-hooks with chisel edges are used, one set of hooks at each end of a girder, as shown in the diagram (*Fig. 12*). Two joists or channels are frequently hoisted at the same time. These hooks apparently are perfectly safe, and, though in constant use, do not appear to slip. They release themselves when the load is lowered. A crane-driver will deposit a load and then unhook the crane-hook from the girder without assistance, by manœuvring the crane; and the Author has frequently seen a driver pick up a girder and hooks again without any assistance. For short joists the same hooks are used singly; but it is necessary, when only one is used, for a man to keep the joist approximately horizontal.

Fig. 12.



CLIP-HOOKS FOR HANDLING LARGE JOISTS.

The causes which enable the American manufacturer to work so cheaply appear to be principally these:—

(1) The workmen, while more highly paid than English workmen, also turn out a much larger quantity of work.

(2) The arrangement of the works is more carefully thought out, and labour-saving appliances are more used.

(3) There is more method, and probably more scientific knowledge in the drawing-office.

(4) The works run night and day.

(5) The templating is reduced to a minimum, by care in the drawing-office, and by the use of automatic machinery and stops and guides.

(6) Obsolete machinery is turned out of the works as soon as it is superseded by anything better.

(7) All tools are kept in a state of perfect efficiency.

(8) Railway freights are much lower than in England.

The responsibility for the small output per man in England rests only partially with the manufacturer. The action of various labour-organizations in insisting on the employment of skilled labour on machines where it is not necessary, and the opposition to the introduction of any machinery which may reduce the number of men employed, or increase the output of the individual workman, fetter the manufacturer in any attempt he may make to increase the work done by each man. The conservative instinct among workmen in England is also opposed to anything new; and it is difficult to get them to give any innovation a fair trial, especially if it does not succeed at once. It should be possible, however, to introduce many improvements which would increase the output; and there are several lines on which this may be done.

A careful arrangement of the works is desirable, so as to avoid all unnecessary handling of material, and to give ample facilities for whatever handling is absolutely necessary.

The drawings should be completed in the drawing-office and contain all necessary information for carrying out the work, so as to render it unnecessary to keep a number of skilled template-makers to supply deficiencies in them.

It should be clearly understood that, if a machine does not work economically and well, it is bad policy to keep it lumbering the works.

All machinery in the works should be kept in perfect order; blunt tools mean bad work and increased cost.

Ample power to drive all machinery is an absolute necessity. Accumulators down when drawn on by presses and riveters at the same time; boilers losing steam, or priming when the works are in full swing; electric lights burning dim, because there is no spare current when cranes are heavily worked—all these mean loss of output, and labour standing idle; and where works have been enlarged, the boilers and engines are frequently supplemented only when their failure to respond to the additional calls on them makes it absolutely necessary.

The saving which can be effected by systematic methods in the drawing-office, and by designing work so that as many small parts as possible are interchangeable, and can be made with stops and guides and multiple punches, or be punched from one template, will be seen on consideration to be very great.

Any means of reducing the number of platers required will at once reduce the cost of the work; and in this particular the American system seems to be far in advance of that prevailing in this country.

The results obtained at Pencoyd, where only 29 template-makers are employed, and an output of over 6,000 tons per month has been achieved, when compared with the corresponding figures for any English bridge-yard, will at once show what a vast saving is possible.

The advantage of being able to turn out the small portions of the work, such as stiffeners, web-covers, angle-cleats, etc., without having to mark each piece, and shear and punch it to those marks, is enormous; and the gain in accuracy, speed, and reduction of cost, is equally great.

The use of the spacing-punch for main angle-bars and flanges entirely obviates the necessity for the costly operation of making wooden templates, and marking each angle-bar and plate from these. The ever-recurring trouble caused by the wooden template expanding with moisture, and the steel with a rise in temperature, and by the consequent bad fitting, is entirely done away with where the spacing-punch is used; and the trouble caused by the lengthening of an angle-bar when punched is reduced to a minimum in this machine by the angle-bars being kept straight while they are punched.

The advantage of having the bridge-shop entirely roofed in, and with a dry, clean, boarded floor, can hardly be realized unless seen.

The use of small electric cranes and hoists, in place of large gantries or Wellington cranes, enables the works to be covered in at a cost which is much less than would be necessary in most English bridge-works.

The accuracy of the work renders erection at the works unnecessary; and this is never required or done, except very occasionally when specified in the case of European orders.

The small space occupied by the bridge-shop is also noticeable, when the output is taken into consideration. There is no crowding, but all the space is utilized. Meals are served to employees of the company in a large, well-kept restaurant, at extremely low prices; all classes, from the heads of departments down, frequently get their luncheon at this restaurant.

There is a separate erection-department, which is supervised by fully qualified engineers.

The Paper is accompanied by drawings, from which Plate 1 and the Figures in the text have been prepared.

Discussion.

The PRESIDENT, in tendering the thanks of the Institution to the Author for his communication, remarked that it was a Paper which would go home to many at the present time when so much thought and attention was being given to improved methods of production and construction, and when the Institution had recently set on foot a committee for standardizing the various sections of iron and steel, which committee was now investigating many subjects connected with the question of standardization. The President.

The AUTHOR observed that the illustrations in the Paper were not intended to be working-drawings, but simply diagrams to make clear his meaning. He had endeavoured to state the facts as he had found them and not to draw any more deductions than were absolutely necessary. He had limited the Paper entirely to a description of the Pencoyd works, because those works were an example of very good American practice, and certainly showed remarkable results in the way of large output and low cost. At Pencoyd he had been looking after the construction of twenty-six viaducts for the Uganda Railway, made, not to American standard patterns, but to designs prepared in Sir Alexander Rendel's office. The amount of work, per annum, usually done in England as compared with the figures given in the Table (p. 61) were—draughtsmen, about 1,000 tons; men in bridge-shop, 20 tons to 30 tons; templaters, about 500 tons. He based those figures on his own experience, and they had been checked by one or two men who knew something about the matter in this country. The figures were such that anyone conversant with the subject could easily check them from his own experience. It would be observed that draughtsmen turned out a little more in England than they did in America, but in America more work was put into the drawings, and to illustrate this he exhibited a few blue prints of actual working-drawings made at Pencoyd. A table was given on each drawing showing the sizes of all material required; and the steel was ordered from those drawings. The table went into the works with the drawing, and the workman could pick out his material from the list, there being thus much less possibility of error and no delay. In England the output of a man in the bridge-shop was between 20 tons and 30 tons per annum, but at The Author.

The Author. the Pencoyd works the average for the past six years had been 115 tons. At Pencoyd the templaters accounted for 2,366 tons per annum, while in England the figure was about 500 tons. Those figures showed that there must be something radically wrong with the works, the management, or the workmen in this country; whatever it was, it must make competition extremely difficult when one set of men turned out five times as much as another. But the whole question of cost was not confined to the cost of labour only. Workmen in America were paid between two and two-and-a-half times as much as those in England, and they turned out five times as much work; so that labour there was much cheaper than in this country. For the sake of argument it might be taken that the capital value of works would be approximately proportional to the number of men employed; and, on that assumption American works not only turned out five times as much work per unit of capital as works in England, but, as they worked day and night, they really turned out ten times as much work. The great bugbear of the manufacturer in every country was the fixed charges, which had to be added to every estimate, viz., interest on capital, taxes, expenses of management, office establishment, advertising, etc. Working on the American system the fixed charges were only about one-tenth of the amount of such charges in England per ton of work turned out; and the charges for coal, water, oil, depreciation and repairs, probably only one-fifth. Totalling up the cost of labour and charges, the American manufacturer could work at a much cheaper rate than the English manufacturer. In conclusion he wished to express his thanks to Sir Alexander Rendel, K.C.I.E., M. Inst. C.E., for the loan of the drawings, and to Messrs. Wölfel, Cadmus and Frosell of the American Bridge Company for the facilities they had afforded him for viewing everything that could be seen, and for furnishing him with the statistics of output; also to Mr. J. T. Daly, of the Horseley Company, who had kindly furnished him with figures corroborating those which he had quoted.

Mr. Robertson. Mr. F. E. Robertson thought the Paper was a valuable contribution to the discussion on foreign competition, which he feared could not be settled by roundly asserting that all foreign manufactures were so bad that they were put quite out of court. A sufficient explanation of the cheapness of American manufactures appeared to be found in the labour-charges and the fixed charges, which fell much more heavily on the smaller output. Probably the smaller output which appeared to obtain in England was equally due to want of system and appliances in the shops, and to unwise

action on the part of trades-unions. He remembered a striking instance of the former in connection with a very large contract for bridgework with which he had been connected some years previously. The firm which had taken the order had been an excellent firm as regarded the quality of their work, but their plant and methods had been antiquated. They had had a very poor collection of drills of all sorts and sizes, and but one steam riveter to do the whole of the work. After the work had gone on for a short time, he had been obliged to show them, by simple arithmetic, that at the rate of progress their resources admitted of they would be some years over the job, and that consequently, unless they took steps to lay down a reasonably adequate plant the delay clauses of the contract would have to be enforced. Thus constrained, they had laid down a number of drills and some hydraulic riveters; and shortly afterwards they had candidly admitted that the expenditure was the best investment they had ever made. Lately another instance of inadequate appliances had occurred in the case of a tolerably large contract for trestle viaducts very similar to those alluded to in the Paper. Here again the contractors had been a very good firm, and there had been nothing to complain of with regard to the quality of their finished work, but they had proceeded to make the butts of the trestle legs by the time-honoured process of chisel and hammer and file, although the designs had been made expressly with a view to cheapen the work by duplication. He thought it could scarcely be contended that that was an adequate arrangement; or that work done in such a way would be as good or as cheap as work turned out by proper plant. Another point in which the bridge-yards in this country seemed to be deficient was in the want of adequate covered space, a defect which in the English climate was a constant source of delay and expense. The way in which bridge-yards had grown from small beginnings formed a reason for that; but there must be a point at which it ceased to be a reasonable excuse. Waiting on the rolling-mill was also a disadvantage from which the British bridge-builder suffered, and from which the large American yards, having their own rolling-mills, were tolerably free. He did not think that higher railway charges were of much weight because the American rolling-mills were on the spot at the bridge-yard. The detailed and, as he believed, unprejudiced statements in the Paper formed a good standard by which to criticise British methods in those points where the British output seemed to fall short of what was obtained in America. Mr. Robertson

Mr. Gribble. Mr. T. G. GRIBBLE remarked that he had had something to do with bridge-design and construction in the United States some years previously, and he thought that one of the reasons which militated strongly against the standardization of plant with the manufacturers in the United Kingdom was the difference between the systems in vogue in the two countries. Bridge-works in this country had no designing engineers on their staffs, while in America some of the best engineers were connected with bridge-building firms, and in many cases, except, perhaps, in the most important works, the independent engineer designed only the general lines of a structure and gave the stress-sheet to the bridge-works, leaving all detail to its engineering staff. Such procedure helped the American shops to standardize; they knew just where their own types of stiffeners, eye-bars, etc., could be put in. In England the continual complaint was that the great diversity of design, even in common girder-work, greatly hampered a firm having a few useful machines. Sometimes there were grievous complaints about unworkable designs, especially in regard to those received from municipal engineers, who often appeared to be architects doing a little engineering by the way. They would put in, say, a little flange angle with a 1-inch rivet in it, with no possibility of putting a cover on. He did not think it would prejudice the profession of the civil engineer at home if methods somewhat similar to American methods were adopted here. In America the bridge-engineer had plenty of scope, whether he went into the service of a bridge-company or acted independently.

Mr. Webb. Mr. F. W. WEBB, Vice-President, observed that he had used for some years the lifting-crane described by the Author, for lifting heavy plates, and had found it very useful. He had not had much experience with ordinary bridge-building, but had had some breakdown jobs, especially in August, 1879, when the Llandulas viaduct on the London and North Western Railway in North Wales had been washed away. He had manufactured, from the pig-iron, the steelwork for the reconstruction of this viaduct, spanning a distance of 224 feet, in the course of seven days; and he thought that would compare very favourably with any work done before or since. An account of the rebuilding of this bridge, with illustrations of the work in progress, had been published.[1]

r Douglas x. Sir DOUGLAS FOX, Past-President, remarked that he had had a great deal of experience of American and English design and manufacture in connection with bridgework. One point often

[1] *Engineering*, vol. xxviii. p. 343.

forgotten was that the circumstances under which American bridges were designed and used were generally very different from those which surrounded bridges designed for an old and densely-populated country like England. It was true that, from London, bridges were sent almost all over the world, and British designs for use in the Colonies and India would compare in simplicity and in interchangeability with any that could be found in the United States. When dealing, however, in this country with intricate questions of differing angles, of a few inches of span, of limited headway, and the many other questions of that kind which continually arose, standardization was absolutely impossible. When some six hundred spans on the Liverpool Overhead Railway had been handed over to his firm by the Dock Board, he had been told that they had been standardized, that the plans had been so arranged that it would be necessary to have only three types, and that about six drawings would do the work. Before the work had been finished the drawings had numbered over one thousand. English engineers could design simple bridges for simple circumstances, for the Cape or elsewhere, and could send out 150-foot, 100-foot, 40-foot, or 30-foot spans, which could be put up anywhere. Every part of those bridges was interchangeable, and the parts could be assembled with the greatest ease; but that was an impossibility when dealing with bridges in places like London, where the engineer was tied by all sorts of clauses and conditions. In an old country it was exceedingly difficult for bridge-builders or other manufacturers to be up-to-date. It was a very serious matter for them, and engineers sympathized with them, and as far as possible tried to simplify the work for them. He was quite sure there was a great effort on the part of the engineers in Westminster to meet that difficulty, and if the bridge-builders would only put their shoulders to the wheel and have the best possible arrangements in their works, he had no fear but that Great Britain could hold its own against the world. Sir Douglas Fox.

Mr. R. Moreland, Jun., remarked that his firm had been engaged in constructional work for some years, and having decided three years ago to enlarge their works, they had taken 5 acres of ground at Silvertown. They had erected overhead gantries of 45 feet span, served by electric cranes. At one end of the site was the river, at the other end the Great Eastern Railway. Most of the material was brought by the river, and unloaded by the electric cranes, of which there were four, the longest gantry being 600 feet long by 45 feet wide. The stock-yard consisted of two bays of 45 feet span and 230 feet long, and two bays of 45 feet span and Mr. Moreland.

Mr. Moreland. 140 feet long. Next came the machine shop of about the same size, served by overhead electric cranes. All the machines in the machine shop were driven electrically. At the other end was a loading-yard 200 feet by 45 feet. The shop had been put down with a view to giving quick delivery. In 1900 the firm with which he was associated had been asked to design the steel construction of the Imperial Theatre, under the architect, Mr. Frank Verity. On the 22nd December, 1900, instructions had been received to proceed with the work, and 1 week had been allowed for making the drawings. On the 1st January all the drawings had been in the shop. The constructive work had consisted of two tiers and part of the roof, as the Imperial Theatre was an old house with a new interior. The work had been completely finished by the 14th February, that was, in 7 weeks. Since then the firm had completed a large job at Harrod's Stores, comprising 1,100 tons of constructional steelwork. The order had been given on the 30th July, 1901, and erection had been commenced on the 26th August; three floors, containing 600 tons of steelwork, had been completed in 5 weeks, and the remainder had just been finished and erected.

Mr. Rigby. Mr. H. Rigby observed that, as General Manager of Messrs. Joseph Westwood & Co., Limited, he had read with considerable anxiety, and sometimes with much pleasure, many of the statements that had appeared in the Press from time to time during the past two years with regard to American competition, especially in bridgework. Many of them were undoubtedly of no value at all. The Americans started bridge-building with the British manufacturers' experience behind them, and it was only those who possessed very large capital who could put down a bridge-yard similar to that described by the Author. It would probably be found that many of the operations which the Author had described were now, and had been for the last 40 years, carried out in this country. Thirty years ago, when he was with the firm of Lloyds, Fosters & Co. (the Patent Shaft and Axletree Company), many of the up-to-date arrangements described in the Paper had been tried and discarded because they had proved to be unworkable. Multiple drilling had been tried, but so many drills had been broken in the process, and the machines had had to stop work for so long a time, that it had practically had to be discarded. The better and more workmanlike process was to assemble the punched work under single radial drills and drill right through; in this way Messrs. Westwood & Co. could drill twelve or fourteen plates at a time, and if it was possible to drill fourteen holes in 45 seconds, he did not think that was much behind American practice. With regard to the

Author's remarks as to the expensive part of bridge-building, angle-smith's work, he had need of an angle-smith perhaps once in 3 months, to do an odd job. The whole of the smith's work was done by modern hydraulic machinery, and work which a short time ago had cost 2*s.* 6*d.* could now be done for 2½*d.* American competition was a serious subject, and one on which his directors and the workmen had had many conversations. As to riveting, he remembered a time when a day's work in this country had been considered by the Society to be thirty-two score, and men had only been allowed to work time-and-a-quarter, eight hundred rivets being the maximum day's work. It was no uncommon thing now at his yard—where Union rules were not adopted and prices were arranged with sets of men—for a set of four men to earn in one week £16 in wages, and the firm were pleased to pay the money, because the men earned it. A piece-work price was settled with the men, and if they could earn more than had been supposed, the firm was satisfied to let them do so. The yard referred to occupied an excellent position in regard to prices. The firm paid high wages to its men, but at the same time it obtained a corresponding amount of work out of them, and, as the firm and the men worked cordially together, they formed a happy and united family. What was good for the men was good for the masters, and vice versa. If that principle were carried out more generally, and if the managers and foremen made themselves better acquainted with the men and the work they were doing, competition would be on fairer lines than it was at present. The Uganda viaducts which had been mentioned had been tendered for by his firm, but their tender had not been accepted. No one had yet heard how much profit the American bridge-builders had made out of the work. The bridgework referred to by the Author was a first-class piece of work, one of the finest jobs he had ever seen turned out of Westminster, and he had tendered for it very keenly indeed. One reason for the loss of contracts was that many English firms did not care to send their workmen out of the country and take the responsibility of erecting a very large bridge in, say, Central Africa. Many contracts such as that simply meant loss to a firm and brought it to bankruptcy. He would be glad to hear what became of the American bridge-builders who took a contract and lost £60,000 or £70,000 over it. He had it on good authority that the American firm which had built the Burma viaduct had lost such a sum on the work. He had never heard of a bridge-builder in England who could afford to do anything of the kind. Mr. Rigby.

Mr. Rigby. From what he had been able to observe, and to ascertain from those who visited the United States, he thought American competition need not be feared. He had been requested by his directors to visit the States for a couple of months to see what he could find out, and, when he could get the time, he intended to do so. If bridge-builders in this country would only keep level-headed and apply themselves to their work, there was no need for them to lose anything. At the time when so much had been heard of bridge-building in America, Sir Benjamin Baker had asked him to submit a price for the centre span of the Hopetown Bridge, a pin-connected link type of structure, full of work, even the floor being composed of corrugated plates ornamented with circular plates on the outside, forming a kind of cornice. Such a bridge had a very large amount of work in it and little weight. Sir Benjamin had required the bridge within 6 weeks, and Messrs. Westwood and Company had undertaken the work under a penalty. In 18 days the bridge had been passed, and in 28 days it had been shipped and paid for. Sir Walter Peace, the Agent-General for Natal, had asked him to build thirty-nine bridges at the time when the Boers had destroyed a considerable quantity of bridgework in northern Natal, and in competition he had undertaken to do it in 13 weeks. It had been done in 12 weeks and 4 days. The Author spoke of a bridge-yard turning out 6,000 tons to 10,000 tons of bridgework per month, but the whole thing was absolutely ridiculous and preposterous, and in saying that he was speaking as a bridge-builder and not as a joist-manipulator. It was easy to obtain a quantity of joists and put two or three holes in them, and work turned out under such circumstances on the other side of the Atlantic might well amount to 60,000 tons or 70,000 tons a year; but speaking of bridgework in the ordinary way, what did 60,000 tons or 70,000 tons represent? It all had to be planed, riveted and drilled, and where was it possible to find riveting-plant of a capacity of 60,000 tons or 70,000 tons per annum to start with? He admitted that owing to the standardization of American bridges there was probably half the weight in links, which brought the figure down to 40,000 tons. If two thousand rivets per day were put in by one machine and 40,000 tons of bridgework was turned out, it meant at least thirty riveting-machines working night and day, and he could say without hesitation that at Pencoyd they had not a tithe of the number. The Author said that much of the plate material used in America had milled or rolled edges. A gentleman who had spent a long time at one of the bridgeworks in America had assured him that in plate girders they never

cared there about the butt joints, and that he could put his hand edgewise between the butt joints, from the top to the bottom of a plate-girder web. That was workmanship in America: in this country the first time the inspector came round that job would be scrapped. It was not possible to throw the work at a few machines and say, "Make that." Work must be manipulated by manual labour. The best machines the world could produce had to be guided skilfully and intelligently by the best labour obtainable. The cause of non-success in bridge-building in this country was the fact that manufacturers were hampered by too many varieties of requirements, with absolutely unworkable specifications often written by men who had never been inside a steelworks and knew nothing whatever about the subject. Clauses were put in with regard to machining and manipulation which would be all very well if they could be carried out, but they could not; and the manufacturer was at his wits' end to know how he could show the work to the inspector when he came to examine it. He hoped the time would come when the manufacturers would have more help from the engineers of Westminster than they had had in the past. There could be no doubt that the finest bridgework that had ever been turned out had been made in this country, and it had been brought to that state of perfection by men who knew what they were about. What had been the condition of bridgework before Sir Alexander Rendel had taken it in hand? The structures of Sir Douglas Fox were structures any manufacturer could tender for with pleasure; and the work of Sir Alexander Rendel was so plain that no working-drawings were required. Five thousand tons of work might be ordered from such designs in one morning. In some other cases it would take 5 years. Those difficulties did not crop up in America. Mr. Rigby.

Sir GUILFORD MOLESWORTH, K.C.I.E., remarked that from his own examination and from the reports of his officers he could entirely corroborate Mr. Rigby's statement as to the excellence of the work turned out under his supervision by Messrs. Westwood & Co., a firm which had supplied a large number of bridges to the Indian State Railways. The work had left nothing to be desired either in workmanship or in finish. He thought that if all the English workshops had been under such managers as Mr. Rigby, with non-union men, freed from the paralyzing influence of trades-union rules, less would have been heard of American competition. He wished he could lay the flattering unction to his soul that American competition was, as Mr. Rigby had said, of no account; but ugly facts constantly cropped up which brought home the Sir Guilford Molesworth.

Sir Guilford Molesworth. conviction that it was a serious evil, and one which was on the increase. It was common knowledge how the Americans had carried off in competition contracts for important works in India, Burma, Egypt, and Uganda; and that seemed to be going on with increased intensity, for a Reuter's telegram[1] from New Zealand dated the 30th December, 1901, stated: "The Manawatu Railway Company recently invited tenders for a steel viaduct. The price quoted by American builders was one-fourth of that demanded by English firms. In consequence of this the New Zealand Government has decided to send to America all future orders for steel bridges." The difficulty was not confined to bridge-building; it pervaded more or less—in most cases more—nearly all British trades—iron, steel, cutlery, wire, tin-plate, electrical appliances, textile fabrics, boots and shoes, and innumerable other articles. As to locomotives, the Americans had not only supplied India, Egypt, and Uganda, but they had actually invaded the English railways and had sent locomotives to this country. In 1890 upwards of 300,000 tons of tin-plate had been exported to America, but that export trade was now almost extinguished, and the Americans were importing into England a large quantity of tin-plate. It was folly to be blind to these facts, because by so doing the way to improvement was barred. He held that British manufacturers and British workmen could still hold their own if they had a free hand: but they had not a free hand; they were handicapped in every way. Great Britain was too apt to neglect the teachings of the past. In these vaunted days of the Twentieth Century, although many advances had been made in science, the masses seemed to have made very few advances in common sense. Twenty-five to thirty centuries ago Æsop had tried to impress upon his countrymen, by means of his fables of "Killing the Goose that laid the Golden Egg" and the "Belly and the Members," how the interests of capital and labour were identical, and that if they were hostile the result was disastrous. He might refer to an episode which was not quite ancient history, but nearly so, viz., the great strike of the Amalgamated Engineers in 1851. At that time he had been an apprentice at Sir William Fairbairn's works, and had been a "knobstick" as it had been termed then, or a "blackleg" as it was called now—in other words, one who worked while the other men were out on strike—and he had had to be personally conducted by the police to and from the works. During the interval between the first warnings of the strike

[1] *The Times*, 31 December, 1901.

Sir Guilford Moleswortb.

and its actual outbreak it had been almost the only subject of conversation among the workmen, and he had had many opportunities of talking with them on the matter. Their discontent at the proceedings of the trades-unions had been very great, and their repeated remark had been: "Why cannot they let us alone? We are doing very well as we are." He had asked one of the most intelligent of the men why he and other men like him did not get on to the Councils of the trades-unions and infuse some common sense into them, and the man had replied: "What can we do? When we have done our day's work we want to go home to our wives and families; we do not care to go blethering about in the pot-house. It is the pot-house chap with the gift of the gab who influences the Unions." He had invariably found that those men who talked the loudest about the rights of labour and the wrongs of workmen were the idle, dissolute men—the inferior workmen. It was not surprising that when inspiration was drawn from such sources the policy of the unions should be narrow, and that an endeavour should be made to place limitations on the output of labour. The demands of the trades-unions at the time he referred to had been for the abolition of overtime, of piece-work, and for several other things which tended to the limitation of labour. He had been told by many of the men that overtime was very popular; it enabled a man with a large family to tide over difficulties which otherwise he would have been unable to meet. Piece-work was extremely popular with the good men, as it enabled them to take small contracts, and by degrees to raise themselves from the position of workman to that of master. In evidence before a Select Committee of the House of Commons on the subject of strikes he had given the following extracts from one of the rules which had caused the strike:—

"Rule No. 224.—Systematic Overtime and its Discontinuance.

"*Piecework.*—(1) In order to secure to our members the general prospect of employment we repudiate systematic overtime as being the cause of much evil, through giving a number the privilege of working more than a legitimate week's time; whilst so doing deprives other members of situations, producing much domestic misery, and causing a great expenditure of the Society's funds. We therefore authorise the Executive Council to take steps for its immediate discontinuance by issuing a General Order for all districts simultaneously to adopt this resolution. Any member refusing to comply with this resolution renders himself liable to be excluded. (2) That the same steps be taken to abolish piecework, to destroy the practice of working more than one lathe or machine."

The concluding words referred to the self-acting machines, of which one man could work several. Exclusion involved not

Sir Guilford Molesworth. only loss of all previous subscriptions, but also social ostracism. The men were tied hand and foot by the unions. The strike in question had gone on, entailing a terrible amount of misery on the men and ruin on the masters, and it had enabled America to get its first grip of the trade. Fortunately, the Amalgamated Society had been badly beaten, for if the demands had been conceded the trade must have been ruined. Within the last decade, the same society had acted again in the same way, the struggle having the same result; but again America had been enabled to get a tighter grip on the trade of this country. It was extraordinary how the labour-leaders openly preached the doctrine of the limitation of output. He had seen, on the authority of the secretary of the National Free Labour Association, that Mr. John Burns, M.P., had stated to an audience of workmen that it was their business to sell their labour at the highest price, and their duty to work as few hours as possible. Mr. Keir Hardie, M.P., had told an audience of men that their best interests lay in the direction of getting as much money as possible for as little work as possible. When such principles prevailed, how was it possible to compete with the foreigner? Mr. Schwab, the president of the Steel Trust in America, at a great labour-conference at New York in December, 1901, had declared that labour-unions would fail in the same way as trusts had formerly failed, so long as they adopted as their fundamental principle the restriction of output; and had expressed his belief that English labour-unions had been the cause of the decadence of English manufacturing industries. Again, according to the Press, Mr. Schwab had also recently said that the attitude of labour in England would never permit mills and factories to be worked as they were worked in America, and that careful survey of the whole field seemed to show that the English workman received on an average less than one-half of what the American received year in and year out; and yet the cost of production had been nearly doubled, solely by the action of the labour-trusts which predominated in England. The same policy pervaded other industries. The following rule appeared upon a bricklayer's card:—

"RULE 5.—You are strictly cautioned not to overstep good rules by doing double the work you are required and causing others to do the same in order to gain a smile from your master. Such foolhardy and deceitful actions leave a great number of good members out of employment the year round. Certain individuals have been guilty who will be expelled if they do not refrain."

The result was limitation of the number of bricks laid. While 450 bricks per 9-hour day was said to be the average work of

the British bricklayer, Mr. Stewart, an American working at Manchester at the Westinghouse works, had got out of his men 1,800 bricks per 9-hour day per man, and 2,500 bricks per day per man on the plainest work. He was informed that the London County Council was content with 330 bricks per day. In the boot trade there had been recently a riot in Northamptonshire. Managers had been stoned, and the men had definitely decided to go out on strike if the manufacturers persisted in retaining the machinery imported from America. That might be contrasted with what was being done abroad. He noticed that in Vienna in December, 1901, the Minister of Commerce, acting on the advice of the National Council of Labour, had decided to buy American machinery for manufacturing boots and shoes, and to supply that machinery gratis to Austrian manufacturers, as the only means of saving from utter ruin the Austrian boot and shoe trade, owing to competition with America. Foreigners were carrying out the opposite policy to that which was carried out in this country. Apart from the actual limitation of labour the loss by strikes was appalling. The labour-reports stated that the amount of labour lost in 1893 in strikes had amounted to 31,200,000 days; and that figure did not represent the losses to the manufacturers, for a strike curtailed their capital and prevented them from launching out into that expenditure which was so necessary in carrying on works in competition with America or other foreign countries. He thought trades-unions would be very useful if they kept to their proper sphere, if they were defensive instead of aggressive. British labour was the best labour in the world, and the British master was the best master in the world, if these were only untrammelled; but as it was, the British labourer, under the paralyzing and degrading influence of the trades-unions, was becoming a slip-shod man who took no interest in his work; a degraded man who made the labour of England the most expensive and at the same time the least efficient labour in existence. If British trade was to be saved, the only thing to be done was for masters and men to enter into a strong combination to throw off the terrible tyranny which was killing the country's trade. **Sir Guilford Molesworth.**

Mr. Ewing Matheson considered that it was extremely useful to have international comparisons made, and especially interesting when the other side was the United States. He was very sorry to hear Sir Guilford Molesworth accept, to begin with, the superiority of the United States as a matter to be taken for granted, and as one that, though it might be excused a little or explained, **Mr. Matheson.**

Mr. Matheson. was none the less a fact. Sir Guilford had spoken of a bridge in New Zealand which had been supplied at one-fourth of the price any British manufacturer would offer, but he had mentioned nothing with regard to the conditions. It would be interesting to know what kind of bridge it was, of what design, and what were the conditions. A bare statement that the contract had been taken at a quarter of the price was not evidence one way or the other. With regard to the Paper, the whole question seemed to be dominated by labour, and it was continually being said that the American workman was superior to the British workman. Mr. Matheson had been in the United States often and in many of the principal shops, and he had really come across very few American workmen. All the best men were from Great Britain. The man at the steam-hammer came, say, from Middlesbrough; the man at the rolling-mill came, say, from Sheffield or Workington; and the engineer from Leeds. The manufacturer wanted the best emigrants he could get, and he looked upon them as capital out of which he could make money. Still they were British craftsmen who did much the best work in America. They were stimulated by the climate, had meat three times a day and used up their lives quickly; but they had no more total energy than the workmen of this country. It was all taken out of them by the time they were forty-five, and then other emigrants arrived from England to take their places. The proprietors of the works had the men ready to their hands, men who worked desperately hard and better than those who had served an apprenticeship in America, and they received better wages. It was very interesting to those members who were concerned with bridge-building to see the plan of the Pencoyd yard (Plate 1), which was very conveniently placed between a railway and a river. He would not himself have cared to choose such a site, because it was wedged in tightly between two places of different levels where it was impossible to extend a foot sideways, although there was room to extend lengthwise. The Paper was entitled "Workshop Methods," and he observed that the diagram referred to a bridge-yard, but it was not a bridge-building place at all. It was a place where certain girders and pieces of girders were made, which, when carried away, could be built into bridges. In this country manufacturers were asked by engineers, rightly or wrongly—he thought rightly—to make the bridges and to show them as such, and then to take them away and put them up in place. To compare the tonnage of work of the size turned out in that yard with what was done in this country was fallacious, or, at any rate,

the comparison was not complete. The Author said that he had had considerable experience in England before going to Pencoyd, and Mr. Matheson would like to know the length of that experience and the kind of works in which it had been obtained. There was too often a tendency, in visiting a new country, and coming under the glamour of new and interesting objects, to compare the new things favourably with those of more ancient date in the country from which the observer came. There was not much in the Pencoyd works that was new, although the arrangement of the processes was extremely good. A rotary planing-machine was shown as if it was something novel and peculiarly American, but such machines had been seen in England in considerable numbers, and on the whole were not considered very successful. With regard to the crane-hooks for lifting beams, he hardly knew a quarry in Great Britain where stones were not lifted by these self-acting grabs. Reference was also made in the Paper to the wonderful machines in America for upsetting eye-bars, or, as they were called in this country when they were used, links. Some of the machines in America were very powerful, hydraulic pressure of nearly 1,000 tons being used sometimes for upsetting the end of a bar. Between 1865 and 1875 there had been a large output of bridge-links in this country. He believed that the late Sir George Berkley, K.C.M.G., Past-President Inst. C.E., in his time had shipped no less than 30,000 tons of such links to the Great Indian Peninsula Railway and other railways in India under his control, all the links being made at one works in London on the Thames, which had been abandoned long ago. The process and machines used in that works had been far better and cheaper than anything existing in any of the American workshops. The works in London had been closed owing to the retirement of the proprietors and to the sale of the site; and as links were no longer ordered in large numbers by English engineers the trade had come to an end; but if they were wanted again he believed they could be made in this country better than in America. The "upsetting" referred to in the Paper crushed the fibre of the steel and was not a good beginning for a link. Any one walking on the footpath across Charing Cross bridge would notice that the tension members, both horizontal and diagonal, were links, and they had been made in the English fashion entirely in the rolling-mill, where the fibre was treated to its best advantage. The Author compared the quality of steel in America with the quality of British steel, but Mr. Matheson did not think comparisons were necessary, because the same kind of Mr. Matheson.

Mr. Matheson. steel was used in both countries—a steel having a tensile strength ranging between 28 tons and 32 tons per square inch. With regard to the workmanship of American bridges, it was always difficult to compare the conditions of one country with those of another, or to present to the manufacturer of one country conditions which were usual in the other. Manufacturers were necessarily guided by the wishes of their clients, the engineers—usually members of the Institution. He had been reading a report from a member of the Institution, an engineer engaged on public works in India, who had had the erection of many bridges received from England and from the United States, the American bridges being made on English lines, with rivets and not with pin-joints. In order to insure the erection of American bridges not put together in the works of the manufacturer, greater latitude had been allowed than would be permitted in England, and the engineer had reported that, unless the rivets were put in in a particular way, so as to fill the large holes, the American bridges were not so substantial. There the difference had told the other way, the Americans having had to conform to British conditions. Sometimes in an American specification there was a difficulty, because the whole of the workshops and processes in England had been made for the conditions which manufacturers were obliged to work under here. With regard to percussion riveters, there were four kinds of riveting-machines used in British bridge-works, steam, hydraulic, compressed-air, and pneumatic percussion machines, and each of them had its proper place. It was quite fallacious to say that one of them was better than another under all circumstances. No doubt the percussion riveter, namely, one which worked like a rock-drill, with a large number of percussions per minute, was useful for rivets of small diameter and where no very tight work was required—in light structures, for instance; but in boilers to be caulked steam-tight, or in other cases which occurred sometimes, when rivets $\frac{7}{8}$ inch in diameter had to go through three, four, or five plates and angles, and a tremendous grip had to be obtained on the plates to hold them together for riveting, a percussion machine of that kind would be quite inappropriate and useless. Therefore, unless information was given as to the kind of work to which the riveter was applied in America, it was impossible to make any comparison of it with the English system. The arrangement of templates was different in America because of the large amount of duplication. In this country the manufacturer was entirely in the hands of the engineer, and if the same conditions prevailed here it would be

found that there were manufacturers as enterprising as any in the United States; at any rate, enterprising enough to go to the ends of the earth and put up bridges. But it would be found that, whenever specifications and conditions had been presented to an American manufacturer in competition with an English manufacturer, those specifications and conditions had been altered, and the two countries were not allowed a practically fair comparison. Bridges as designed in this country could not be made in the Pencoyd bridge-yard. Girders of 70 feet or 80 feet span with plate-webs 5 feet to 8 feet in depth, were not thought of in America. They were all made in pieces, articulated very carefully, and put together with pins at their destination. It might or might not be a better system than that prevailing in this country, but the two things did not admit of a fair comparison. It would be far too long a business to attempt to discuss the question of labour and strikes; but he fancied it was not all joy and happiness in the United States, and that there might be labour-troubles there also. He was very sorry to hear the Author assume that Great Britain was beaten in everything. Some Englishmen thought that when it came to good quality, the British manufacturer could still hold his own; and that when the consul or the enterprising missionary, whose knowledge of engineering was not very deep, talked about adapting English methods to the demands of the buyer, giving him what he wanted—giving him sixpenny pocket-knives instead of good Sheffield cutlery, because the Germans did so—some Englishmen were still prepared to stand on their merits, and believed that in the long run, if the consumer wanted something good, he would come to this country for it. Mr. Matheson.

Mr. ARTHUR MUSKER congratulated the Author on the excellent example he had given of how bridges could be built, and his clear and concise description of the system of building, which hardly left much to be said. He considered that underlying the subject of the Paper there was one leading factor which made competition real and strong. It was an important matter, and was becoming more recognized every day; and he thought that where attention was paid to it this country could easily compete with foreign countries. The point was that foreign competitors built and equipped their works to turn out large quantities of machinery of one class and produced goods by special machinery; or, in a few words, they specialized, standardized and multiplied. Unless this country did the same it was impossible for it to compete. The point for discussion was how to achieve the methods necessary; and in the Mr. Musker.

Mr. Musker. first place he would criticize the Author's conclusions. He did not agree with the Author with regard to the workmen, because he maintained that if the works were equipped according to special and modern methods, and if there were in those works foremen and managers who knew their business, the British workman was equal to the foreigner. That fact was proved by competitors coming over to this country and laying down numerous large works, relying solely on British labour. He agreed with the Author in his other conclusions, but believed he did not go far enough. The question British manufacturers had to ask themselves was, why they did not equip their works in the same manner? The answer was that financial men did not realize the necessity, and managers and foremen had not learned to carry on the work in that way. Financial men were wanted who could realize that more capital was required if factories were to be carried out in a specialized manner. More working-capital was necessary, because larger stock was needed. Managers were wanted who could initiate economical methods of manufacture and who could direct their foremen. Foremen were necessary who could carry out specialized work and who could get the best value out of special machinery, and at the lowest price get the best work on the piece-work or bonus system. Given the money and such men, there need be no fear of any competition. That raised the question of how to produce the men, and quickly. To his mind there were only three ways of doing it. In the first place, men must be bought from competitors and charged with the superintendence of the workmen here; or else men must be bought from competitors, to teach foremen and managers. If that could not be done, managers and foremen must be sent where the work was carried out, to learn the methods adopted. To go on as manufacturers were at present doing would take too long. It was better to take advantage of the experience of competitors than to buy that experience dearly. He advocated, not the teaching of the British workman, but the teaching of his more intelligent superior, because it must be remembered that one manager could, and for his own benefit would, teach twenty foremen, and each foreman for the same reason would teach forty or fifty workmen; whereas if an effort were made to educate a workman or a youth, it was only dealing with a unit, and very slow progress would be made at the wrong end. One thing was certain, namely, that technical education would not produce such men; and the sooner it was realized that something more practical was required the better it would be for British trade. A large amount was being expended all over the country on technical and secondary

education, but the money was being spent by men who did not Mr. Musker. realize what was required, and the youth of the country were being educated by men who were not themselves practical. He suggested that the Institution, the members of which did know what was required, should determine what was necessary, and should let those who were spending this money know its views, so that proper steps might be taken and followed up. Another matter requiring consideration was the English apprenticeship system. Mr. Stewart, of the Westinghouse Company, maintained that the system of apprenticing a boy for 5 years or 7 years and paying him a settled rate of wages, running up to 12*s.* or 14*s.* per week when he was twenty-one, was very bad, as it gave the boy no inducement to improve himself or to work hard, and was entirely opposed to the American methods, where the boy was paid according to what he was worth. With regard to capital, a point not fully realized in this country was that all improvements had to be taken out of capital and not out of profits; otherwise, how was it possible to throw on one side obsolete machinery and replace it with modern? Investors must also learn to put their capital into entirely fresh ventures, relying solely on the fact that large quantities of any class of goods or machinery might be manufactured and sold at a profit if produced in a proper manner.

Mr. H. F. DONALDSON observed that it was satisfactory to hear Mr. Donaldson. manufacturers adopting Mr. Rigby's view that all and everything was very well. On the other hand, it seemed that there was a decided danger in being too well satisfied with the present state of things. That English manufacturers had very strong competition to meet could not be denied. It was absolutely useless to talk about American contractors undertaking work for advertising purposes only, and being satisfied to lose £70,000 two or three times over simply for the sake of advertisement. If the books of those companies were looked into it would be found that there was not a loss, but a comfortable profit. The wish that competitors should lose their money on new ventures was perhaps father to the thought. He read into the Paper three main points for which he might give three main words—standardization, specialization, organization. Standardization was a matter upon which much had been said, and on which much more would be said in this country before long. The Institution had, to the joy of many of its members and of manufacturers, set on foot a Standardization Committee in connection with many matters relating to bridges, roofs, ship-building, etc.; and personally he looked for very great benefit from the results of the Com-

Mr. Donaldson. mittee's labours. Standardization required to be taken up in much smaller matters than he had mentioned, and he might cite one point with regard to which there was a great deal of difference in practice, particularly in the manufacture of machinery—namely, whether the dimension of the spindle or that of the hole was to be the leading dimension. He hoped that some day there would be standardization which would enable manufacturers to know whether a 1-inch bolt was to be 1 inch in diameter or was to go into a hole of that diameter, within limits. Specialization enabled one works to produce large quantities of the same product of the same size. Circumstances and environment in this country did not lend themselves to that sort of production so much as in the United States. At the same time there was a class of specialization which might well be carried out in this country more than was done; that was, the adoption to a larger extent, for more varied uses, and in more shops, of the kind of thing exemplified by the Author's description of machines which worked with stops, marking arrangements, and so forth. Such machines could be made to apply to a great many articles which simply required holes of the same size but with different spacing, or spindles of the same size but different lengths. Such specialization depended upon the design of the machinery; and if the machinery was capable of being adjusted for a large range of dimensions, this country would attain something more in the way of specialization than it had at present. He did not mean that foreign competitors had a monopoly of that sort of thing; there were works in this country which were second to none in their equipment, but there were not enough of them. One of the reasons why so much was heard of American productions was that there were more go-ahead firms, more people ready to put down capital quickly in order to save the labour-bill, than there were in this country. That there were backward firms in the United States he thought was undoubted, and some of them he believed were worse than the worst of those in Great Britain. With regard to organization, it was the organization of a shop which arranged that the sequence of the operations upon any piece should involve its travelling in one direction only, or at most in two directions, which should never cross. In the instance described in the Paper the movement of the pieces was lengthways of the shop and across the shop, never going backward, but always forward. That was a point which was overlooked in many classes of work in this country, with consequent confusion, extra labour in handling, and extra selling-price. He

spoke with some knowledge, for it was his duty to keep himself well informed as to what different manufacturers were doing in engineering works, and his remarks embodied what had struck him in many of his visits. The Author referred to one man handling plates in America which it took three to five men to handle here. He did not know whether he was right in supposing that the handling was done on the goose-necks, or whether there was any overhead gear. If there was any overhead gear it was not represented in the diagram. He would like to know whether compressed air or any other overhead gear was used for dealing with plates, angles, or heavy pieces in the immediate neighbourhood of machines. With regard to oil-furnaces, the Author might say something about their efficiency. The pneumatic riveter had been referred to, and he would be glad to know if the Author had seen it applied to boilers. His own experience was that the work was not anything like close enough, even with the heaviest pneumatic tools, to make good boiler-work. There were many cutting tools used in the works, and he also wished to know whether the practice of the shop was that those tools were dealt with by the workmen themselves, or whether they were taken from store and returned when they required to be sharpened or touched up. Mr. Donaldson.

Mr. C. F. DIXON remarked that one point which had occurred to him was the fact that for many years, up to within the past four or five years, bridgework in this country had been hardly remunerative. No protective system existed to enable a high price to be charged in this country, so that work could be sent abroad at low prices. In order to tempt capitalists to put their money into bridge-works, as had been suggested, it was necessary to show a good return; he did not see how a capitalist was to be induced to put his money into an industry unless he could expect a profit. That bridgework was not remunerative was shown by the fact that, until the boom had started some five or six years back, bridge-works had begun to show signs of closing. If it was possible to get such a price as would leave the manufacturer a fair margin of profit, there was no doubt manufacturers would go ahead and put down machinery; but how were they to put down machinery if they made no profit? One of the surprising things in American competition was the price at which the Uganda bridgework had been taken. If he remembered rightly, the price had been £10 or £10 5*s*. per ton, delivered in Africa from America. At the time the price of bridge-materials in England had been about £8 10*s*. per ton. At the lowest estimate Mr. Dixon.

Mr. Dixon. freight would be £1 per ton, which left 10*s.* per ton for making the work and for profit. He had tendered for the work; but, of course, unsuccessfully. He agreed with those speakers who considered British workmen second to none. A large number of the successful workmen in America had gone out from England. The labour difficulty in England would be overcome before very long. Personally, if he could see his way to put down works on the American system, and could get the men to adopt the idea of each man doing his best and working modern machinery to the best advantage, getting paid accordingly, he would be able to compete successfully with America for colonial work. As a matter of fact, in bridgework the idea of making all union men work on one level was not rigidly carried out now; the best men actually did draw higher wages, and the practice was winked at. One of the things which troubled him very much as a manufacturer was the fact that a yard like that described in the Paper, which was very little, if at all, larger in area than the yard he himself worked, and which certainly had not double the machinery, should turn out very nearly ten times as much work as he turned out in the year. It was true the works were run day and night, while his works were only run in the daytime; but, taking it on the basis of daytime only, that would make the Pencoyd output, roughly, five times as large as his. Probably that was due to duplication and to not having to put anything together. He understood the work was made and sent away without being put together; but when a bridge was made in this country it was put together in the yard, taking up room and time, before it was sent away, and probably that made a difference of a good many tons on the yearly output.

Mr. Matheson. Mr. EDWARD E. MATHESON observed that the Paper had considerable interest for him, as about two years ago Messrs. A. Handyside and Company, had sent him to investigate the methods of American bridge-builders, and he had had the privilege of being twice at Pencoyd, and also of visiting the Phœnix works and several others. According to what he had seen and heard, the Pencoyd works were supposed to be the best in the whole of the United States for the class of work for which they were laid out. The first question to consider was the attitude of the builder to the trade, and generally it might be stated that in America the bridge-builders were masters of the situation. They practically all made their own steel and their own designs, and specified to suit their shops, their machines, and their men. They did not erect their work; in regard to painting, they simply covered it with black varnish; and they had a supply of fresh men as fast as others

were used up. In Great Britain the makers were the servants; and there was only one works, or perhaps two, which made their own steel. To put the thing in a nutshell, English manufacturers worked to everybody's specification; they had to erect and to paint to the colour and taste of every individual engineer; they had no fresh supply of men, and they had the trades-unions to fight. With regard to design, it was interesting to watch the progress of American engineers. They were always improving, and, as a rule, in their designs arranged for as few sections as possible, which could be readily obtained and which admitted of simple connection and accessibility for riveting. It was interesting also to see how Americans were borrowing from British practice more and more every year; and now they had discarded the pin type of structure for spans up to at least 130 feet, and the tendency was to continue in this direction. In the colonial designs sent to this country there was considerable room for improvement. Sections would be chosen which did not exist, or which were very difficult to get, or which were made by only one maker; and in regard to forgings, the question of standardizing, of material, and of difficulties of manufacture often seemed to be ignored entirely. With regard to advertising, he was rather inclined to disagree with the last speaker, as he believed the splendid work of the Gokteik and Atbara bridges had been taken at a deliberate loss to get into the market. The Americans were masters of advertisement, and would deliberately, with speculative audacity, tender for a work they knew they were going to lose upon, in order to get into the market and to be advertised gratuitously all over the world by the Press. With regard to overtime, for work that had not to be erected, English shops worked double shift, and his firm had been working double shifts until quite recently for about three years. In England only the best of American works were heard of. There was a large number of second-rate, third-rate and fourth-rate works also. It was dangerous to state, on the one hand, that there was nothing to be gained through American practice, and equally unwise to say that American practice should be copied *in toto*. It ought to be recognised at once that only a compromise was possible. It should be remembered that American manufacturers started in a new field, and could avoid their predecessors' mistakes. It must also be realized that the requirements in America approached more nearly to the requirements in, say, Uganda. There must be a definite and distinct policy recognizing that English main-line finish was wasted in Africa and other similar situations. American prairie land corresponded to the plains of Uganda, but a

Mr. Matheson.

Mr. Matheson. skew bridge, appropriate to London, was out of place on the Zambesi. The point to be urged with consulting engineers was that a different policy was required to meet the different conditions, and British specifications required editing to suit circumstances which closely approximated to American conditions. It was the same in every trade in England. Englishmen had had their way so often that they forgot that new conditions were arising. The Americans, when working to British designs, did not hesitate to simplify the designs to suit their shops, machines and men, in order to facilitate delivery or to cheapen the work. He was certain that the Gokteik and Atbara bridges had not been made to the original specification, and it devolved on consulting engineers to help the British manufacturer to strike out a new policy, and to omit the unnecessary finish. Out of ten points, perhaps there might be two where perfect finish was required, but that was quite unnecessary on the other eight on the Zambesi. Apart from organization, what British manufacturers had to learn, and what was so difficult to learn in a small and old country, was the American methods not only of getting but of keeping business.

Mr. Chatwood. Mr. A. B. Chatwood remarked that the advice had been given in the discussion to lay down new plant. That was no doubt a good thing, but in a great many works he had been in there was something more important, and that was to lay down new brains. There were hundreds of works in this country which had grown from small shops, employing five or six men, whose principal went out to get orders and came home to execute them. Those works had grown to formidable proportions nowadays, perhaps employing five hundred to one thousand men; but the methods which had been suitable, and, in fact, the only methods possible, with a little shop of twenty to thirty men were not the methods by which work could be turned out on a large scale. He was acquainted with works which had started in that way and which were now employing two hundred or three hundred men; when the shop had grown big enough to afford to pay a foreman, say, 30*s.* per week, the best man in the shop had been made foreman, and when it had grown larger he had been made the works-manager. It could not be expected that such a man should get the best results from his men or his machines, or do what a works-manager should do, for instance, with regard to driving-power. That foreman could not reasonably be expected to make a suggestion to his Board that, say, it was worth their while to consider the adoption of electric driving. What was required was some really good works-management. It had

been suggested that English managers should go to America for it, but he did not think that was necessary; there were plenty of men to be had who could manage works satisfactorily and get the best work out of the men, and do it with a great deal of good feeling. But such men required to be paid, and it was not to be expected that a man such as he had in his mind, who devoted the whole of his energy to his profession, and had to work hard in the works, should spend all his spare time in thinking out matters connected with his work, or in reading up what was being done elsewhere, in order to keep ahead, for £3 per week. He had been called to some works a short time ago to examine a planing-machine which had gone wrong. He might mention that the works-manager in that case was in receipt of £700 or £800 per annum. The machine was specially built to plane steel plates, up to 12 feet in length and 4 feet or 5 feet in width, square. The cheeks were separate castings bolted to the bed, and, the machine had a cross slide on it, with the tool-box travelling across. He had examined the machine thoroughly and had found that the cross motion was $\frac{3}{16}$ inch in 4 feet out of square. Needless to say it had now been put right; but it had been in that state for 10 years, and every plate planed on the machine had been planed down the two sides with two tools, and then re-set to an 8-inch square, and as the square belonged to a workman it was not particularly accurate. Mr. Chatwood.

The AUTHOR, in reply, referring to Mr. Robertson's remarks with regard to waiting on the rolling-mill being a disadvantage from which the British bridge-builder suffered, and to the influence of railway charges, observed that at Pencoyd only sectional material was rolled, the plates coming from Pittsburg, Harrisburg or Coatsville, so that railway freights did have some influence on the cost. Sir Douglas Fox's remarks as to the difficulties of designing work in England stated the case so completely on that point that the Author did not think he need say anything further on the subject. Mr. Rigby had observed that many of the operations described in the Paper were now, and had been for the past 40 years, carried out in this country; but the Author claimed no novelty for them; he had simply described them as he had found them; and although they might not be novel, they were not in general use in this country, and he disagreed with the statement that many of them had been tried and discarded as "unworkable." They could hardly be "unworkable," because they were in steady use in America, and were doing very good work. Mr. Rigby had also mentioned multiple drilling; but there was not a multiple The Author.

The Author. drill in the Pencoyd shop as far as the Author knew. The only machines that could be classed as multiple drills were the gantry-drills, which were separate radial drills mounted on a frame moving over the work, each drill being attended to by a separate man. With regard to the output of the Pencoyd Works, the quantity mentioned in the Paper was 3,605 tons to 6,151 tons per month, not 6,000 to 10,000 tons as stated by Mr. Rigby; and, as to joist-manipulating, there was a certain amount of joist-work at Pencoyd, but not a much greater percentage than in any ordinary English bridge-yard—certainly not enough to affect the question. Mr. Rigby's calculation, that if two thousand rivets were put in by one machine per day and 40,000 tons of bridge-work was turned out per year, it meant thirty riveting-machines working night and day, could only be correct on the supposition that 4 cwt. of rivets were put into each ton of steelwork, which of course was absurd; but, as for the Pencoyd Works not having "a tithe of that number," there were at least thirty riveters there, which disposed of the question whether there were enough. That gentleman's remarks also threw a light on the subject of drawing-office methods, and the saving that could be effected by them. He did not think this had been done intentionally, but with regard to Mr. Rigby's description of the drawings for the Uganda viaducts prepared by Sir Alexander Rendel as so plain that no working-drawings were required, and that 5,000 tons of work might be ordered from such designs in one morning, he might mention that when those very drawings had been received at the Pencoyd works the managers had first had made about 200 sheets of detailed working-drawings, and had then ordered the steel, the consequence being that every man had known exactly what he had to do. That was one of the reasons why in America they were able to turn out the work so quickly. As a matter of fact, they had turned out 2,000 tons of steelwork under his inspection in 6 weeks, and fully as much other work in the same time. There had been no pressure about it because the abutments had not been ready. Before the steel had been ordered they had arranged for the ships. They had known exactly when they could do the work and have it ready, and they had absolutely refused to start on it until they had made all their arrangements for shipping, saying that they would not have it lumbering the yard. As to the butt joint in plate girders, Mr. Rigby's information was correct, but his inference from it was not quite fair. Engineers in America did not specify that the web-plates were to be planed and fitted exactly, they relied upon the web-covers to take the stress;

The Author.

but where they had a joint in direct compression they were just as particular about its being planed to a true fit as were engineers in England. It was a question of difference of practice, and he did not think it was possible to take it as a case bearing on the point of excellence or otherwise of manufacture. It was not required by the engineers, and consequently was not done. With regard to the amount of work that the American Bridge Company could turn out, he had had a communication from America in which it was stated that the present capacity of the rolling-mill was 200,000 tons per annum, and of the bridge-shop 80,000 tons; so that apparently they had increased their output since his visit. Mr. Rigby had indicated a preference for assembling work under single radial drills and drilling through twelve or fourteen plates at a time; and thought that, if it was possible to drill thus fourteen plates in 45 seconds, that plan was not much behind American practice. He presumed they would be ½-inch plates at least, which made 7 inches of solid steel; and he certainly thought that if Mr. Rigby could drill through 7 inches of solid steel in 45 seconds he was not much behind American practice. At all events, nothing mentioned in the Paper could compare with this performance. Mr. Ewing Matheson had observed that the labour in American workshops was "mostly English;" if he substituted the words "partly cosmopolitan," he would be more correct. Although there was a fair sprinkling of Europeans, the Author was of opinion that the bulk of the workmen were American. As to all the energy being worked out of the men by the time they were forty-five, and there being a constant stream of fresh labour to replace them, he disagreed with Mr. Matheson *in toto*. The American workman was abstemious, and his home life was much more comfortable and refined than that of the average English workman. Mr. Matheson appeared to question the experience of the Author in recent English practice. He had been for more than five years manager of a large bridge-building works in Manchester, with an output of about 5,000 tons of bridge-work per annum; he had left these works in 1900. Most of the work had been done for English railways. On his leaving the works, some of the workmen had come to him and had offered to put in all their savings, if he would start new works and undertake the management of them. With regard to the clips for lifting joists and channels, it was quite true that similar clips were used for stone in quarries, but their use for the purpose described in the Paper was certainly not common in this country. He had described them because they saved a great deal of labour in slinging. It would never have occurred to him to institute a

The Author. comparison between the American eye-bar and the links on the Charing Cross bridge, and he did not consider that the American class of eye-bar could be rolled. Quite an ordinary size for an eye-bar in the United States was 8 inches by 1⅛ inch in section and as much as 40 feet long, with a head 18½ inches in diameter and a 7½-inch bored hole at each end. He did not see how bars of these dimensions could be rolled, and he did not agree with Mr. Matheson that the fibre of the steel was in any way injured by the upsetting; in fact, the tests which were regularly made on eye-bars showed that there was no injury to the steel in process of manufacture. Makers in the States guaranteed their eye-bars to develop the full strength of the bar, when a full-sized bar was tested to destruction. He had had considerable experience with pin-connected bridges in India, and also considerable trouble with them. He had had surplus pin-connected bridges supplied to him from the Bombay and Baroda Railway, both on the Northern Bengal Railway and on the Punjaub Northern Railway, and had been obliged actually to insert wedges between the links in order to secure even approximately equal tension on them; otherwise many of the links which should have been in tension were actually in compression. He would never have instanced these pin-connected bridges as examples of good workmanship, and they had been condemned wholesale. With regard to percussion riveters, at the Maryland Steel Works he had seen a pontoon dock, probably the largest in the world, for New Orleans, built to the inspection of the United States Government from the designs of Messrs. Clark and Standfield, of Westminster, wherein about 1,500,000 rivets ¾ inch to 1 inch in diameter had all been put in by percussion riveters and the riveting had been perfectly satisfactory. Probably the objection to percussion riveters arose from the fact of light riveters being used for heavy work. Mr. Ewing Matheson was hardly correct in stating that plate girders of 70 feet or 80 feet span were not thought of in America. As Mr. Edward Matheson had mentioned, Americans had discarded the pin type of structure up to at least 130 feet span, and were still discarding it; and a large portion of the output of the Pencoyd Works consisted of large plate-girders which were usually shipped whole. In reply to Mr. Donaldson, there was no overhead gear, the plates resting either on rollers or on goose-necks. The oil-furnaces were the ordinary furnaces burning oil, sprayed with a compressed-air jet. He had not seen the pneumatic percussion riveter used on boiler-work. The sharpening and repair of tools was not done by the workmen; the tools were returned to be repaired and sharpened.

Correspondence.

Mr. A. S. E. Ackermann wished to endorse strongly the Author's view that there was great need for the study of American methods in many engineering matters; and he considered that it was a pity that there were so many persons, even among engineers, who would not realize that the commercial prospects of Great Britain were in danger owing to foreign, especially American, competition, and to the fact that in so many matters, especially mechanical, her methods were antiquated. That there were several first-class firms in Great Britain whose methods could not be improved upon in the present state of knowledge, and that there were a number of very out-of-date shops in America, every one would admit; but it was the general standing of engineering in the two countries that should be compared; and the result of such comparison, it seemed to him, could lead only to one conclusion, namely, that the position of this country relative to America was now greatly inferior to what it had been during the past century, and that this unsatisfactory state of affairs was becoming daily more exaggerated. That this was and would continue to be so seemed to be almost inevitable, largely on account of the difference in the natural resources of the two countries. The area of the United States was nearly thirty times that of Great Britain, while the population was rather more than double; consequently the average density of population was only one-fifteenth of what it was in this country. The natural resources of America were almost boundless, and practically untouched, whereas those of Great Britain were largely worked out; and he would extend the Author's statement that there was more science in the drawing-office by saying that the general standard of education, considered from the scientific and commercial standpoint, was much higher; and that the people in America who were not engineers by training and profession were half engineers by instinct. In a recent tour in the United States, which had extended over 5,000 miles, he had met with some startling indications of industrial activity. For example, the well-known Baldwin locomotive works at Philadelphia had turned out, in the year 1901, over 1,200 locomotives—a rate of nearly four per day. Again, McCormick's harvesting-machine factory turned out 1,200 harvesters per day of 10 working-hours, or 120 complete machines per hour; which was said to be equal to the total production of Mr. Ackermann.

Mr. Ackermann. all the harvesting-machine manufacturers in Great Britain. In the harvesting-twine factory belonging to the same firm, 60 tons of twine were made per day; and the output would shortly be increased to 100 tons per day. At McCormick's factory he had seen six men in charge of sixty-five automatic machines. Turning to an entirely different industry, the total output of coal by America in the last 3 years had exceeded that of Great Britain, and the effect of the use of machinery in this industry was strongly marked. In 1900 the coal cut by machinery in Great Britain had been only 1·48 per cent. of the total, with the use of the total number of 311 machines; whereas in America 19·6 per cent. of the output had been so cut: or, if only bituminous coal were considered, then 25·15 per cent. of it had been cut by machinery, with the use of the total number of 3,907 machines, or nearly thirteen times the number at work in Great Britain: while the number of machines employed in America in 1900, as compared with 1899, had shown an increase of 782 machines. Considering the coal got per annum per person employed, the average in Great Britain for the 3 years, 1898–1900 inclusive, was 300 tons, while the corresponding figure for America was 537 tons; or if bituminous coal only were considered (anthracite not being cut by machines), then the figure for America was 622 tons, which was more than double the quantity got per person employed in Great Britain. On the other hand, the value of the coal at the pit's mouth in America was almost exactly one-half of its value in England; and this fact, he thought, largely accounted for the Americans being able to build bridges more cheaply, even in British colonies, though it was not mentioned in the Paper. That there was serious need for reform in Great Britain was strongly indicated by the large number of successful firms in this country which were to all intents and purposes American, such as the British Westinghouse Co., Messrs. Babcock and Wilcox, the Standard Oil Co., etc. He feared a corresponding list of British firms in America could not be made. To all engineers and others interested in this important question of American competition, he would strongly recommend the articles on "American Engineering Competition," which had appeared in the *Times*, a reprint of which had been published recently by Messrs. Harper Bros., of London.

Mr. Blair. Mr. MALCOLM BLAIR, of Garston, observed that, as long as railway companies and corporations fortunately excluded foreign iron and steel from their work, there would always be a certain amount of bridgework for English bridge-builders. He did not think the Author was entirely correct in his statement that the cheap-

ness of production was the sole reason why American bridge-builders were under-quoting British builders for bridges to be delivered outside this country. He was afraid they were treating this work as surplus production, and were willing to sell at a loss to keep up their output; getting a high price in their own country, and thus obtaining on the whole output a fair average price. This was known to be the course pursued by German and Belgian competitors for rolled material, the average result being usually equal to the selling-price of British material. The prices for the large contract for girders for the Uganda Railway, placed with the American Bridge Company some months ago by the Crown Agents for the Colonies had been published,[1] the lowest price quoted by English makers having been £13 17*s.* 6*d.* per ton, and the American contract price £10 6*s.* per ton delivered f.o.b. in any port in this country. It was idle to suppose that, if this work had been carried out in strict accordance with the very severe specification of the Crown Agents' engineers, it could have been executed at a profit. British manufacturers were handicapped to a certain extent by the free advertisement given to their American competitors by the newspapers in this country; many of these advertisements were exaggerated, and some were untrue. For instance, in almost every newspaper in Great Britain, it had been stated that Lord Kitchener had been obliged to go to America for the Atbara Bridge, because he had been unable to get it erected in time by British bridge-builders; and in addition it had been stated that the country had saved a considerable amount in the cost. The facts were these:—Out of about thirty bridge-builders in this country, only five, he believed, had been asked to tender. Drawings and a specification had been put before these five builders, and tenders had been sent in, no invitation being given to submit alternative designs and specifications. The times offered for completion of the work had not been considered satisfactory, and the Americans had been invited to tender. They had at once declined to do so to the Government design and specification, but had submitted tenders for their own stock design of pin bridge, for which they had the templates and material in stock; and their tender had been accepted. Surely this was contrary to all British ideas of fair play; for many bridge-builders in this country could have done as well as the Americans, if the work had been given to them on the same lines. Such a bridge would not have been accepted by an English railway engineer. The Americans were not always successful Mr. Blair.

[1] *The Engineer*, vol. xci. p. 166.

Mr. Blair. in their competition for work in this country: for instance, the contract for the supply and erection of about 13,000 tons of heavy constructional steelwork for the British Westinghouse Company's new works at Old Trafford, near Manchester, had been secured by an English firm in severe competition with America; though the designs and specification had been made and the work had been supervised by American engineers. He quite agreed with the Author that at the present time, when there was such keen competition with the manufacturers on the Continent and in America, the conduct of the trades-unions in this country was a great menace to its prosperity in the future. These associations were generally supposed to be disciplinary bodies, whose aim was to ensure good and punctual workmen; but he knew of no body of men who lost more time than the members of the Boiler Makers' Society, who were the bridge-makers in this country. A number of them made a practice of losing the first quarter of a day on Monday, and one or two more quarters during the week; and it had now become a custom to convert every Bank Holiday into a three or four days' holiday. The loss entailed by this waste of time to a firm with a standing charge, before profit could be made, of £25,000, could easily be calculated. If complaint were made to the society, the men are supposed to be cautioned or fined, the severity of which measures was generally shown by their losing the first quarter, or perhaps the whole, of the following day. It might be asked: Why not do without these society men and employ non-union men? That had been tried; with the result that when, after much expense in loss of out-put, etc., a staff of non-union men had been obtained capable of turning out satisfactory work, it had been found one day that about three-fourths of the men, by special inducements as to compensation and superannuation, had been persuaded to join the society, which then requested that the remaining non-union men should be dismissed, as the shop had become a union shop. Again, many of the inspectors who examined the work were members of the trade society, and the work of non-union men would not be entirely satisfactory to them The trades-unions encouraged their members to limit their out-put in several ways, viz., by refusing to allow a man to work more than one machine, though in many cases several machines could be advantageously attended to by one man; by reprimanding and fining their members for doing too much; and by interfering in the contracts between employers and employees for piece-work. He quite appreciated the Author's recommendation as to labour-saving machines, and in many works in this country these were being

adopted more or less; but the drastic measures which the Author stated were taken in America with obsolete, or partially obsolete, works, were, he feared, impossible in Great Britain, where capital was not invested in so venturesome a manner as in America; and he could imagine the feelings and words of the shareholders of a large British engineering works, when told by the manager, through the directors, that their works and machinery were obsolete and must be pulled down, rebuilt and re-equipped. British shareholders were not of that nature. As far as he could see at the present time, all that could be hoped for was a better feeling and less jealousy between British bridge-builders, and coalition to put the trade societies in their proper place, and thus secure the abolition of the limitation of out-put and the exorbitant pay received by their members for an indifferent day's work. In conclusion, he would like to draw attention to the fact that the enormous output of the Pencoyd Works, described by the Author, seemed to show that a fair quantity of the steel constructional work turned out was punched, and not afterwards rimered. This appeared to indicate that American engineers were ignorant of, or ignored, the fact that punching steel—even steel of mild quality—reduced its tensile strength by about 9 tons or 10 tons per square inch, in comparison with steel drilled or punched and afterwards rimered to a diameter at least $\frac{1}{8}$ inch larger than that of the original punched hole. While congratulating the Author on the admirable way in which he had put forward his facts, and thanking him for pointing out so clearly to British bridge-builders what he considered to be their weakness, Mr. Blair felt bound to confess that all engineers were not so pessimistic as the Author appeared to be. He believed many thought that British builders would still be able to live for many years to come, even in competition with foreign capital and labour, as long as engineers required a first-class job, and were determined to see that they got it. Mr. Blair.

Mr. A. Buchanan considered that the whole Paper emphasized the great difference which existed between the requirements of the American and the British home markets. It could hardly be otherwise, when the vastness and roominess of the United States, with its great rivers and rectangularly-built cities and towns, was considered and contrasted with this crowded island and its cities and towns built, for the most part, on no plan whatever. These local conditions had necessarily controlled the development of constructive engineering in the two countries, and could not fail to continue to do so, to a greater or less degree. The American Mr. Buchanan.

Mr. Buchanan. engineer could make his site suit his bridge; the British engineer's site governed the form of his bridge. The compactness of the Pencoyd Works bore eloquent testimony to this difference of conditions. Were it necessary in America to erect complete, in the bridge-works, every bridge made, the Pencoyd Works with their large turnout would require almost indefinite enlargement. Again, the drawing-office arrangements would most likely be found to require much modification. Either the staff in those offices would have to be largely increased, or the number of template-makers, as in British shops, would have to bear a much larger ratio to the drawing-office staff. The absence from British home work of repetition of parts (a feature predominant in American work) rendered many of the admirable Pencoyd arrangements much less applicable in British shops. The small number of planing-machines at Pencoyd was very striking, and was, of course, due to the fact that, apparently, the American plate-mills rolled wide plates much as bars were rolled in Great Britain, so avoiding the necessity for any planing, except at the ends of plates. Lastly, with regard to the human element, it seemed clear that the determination of the American workman to consult his own interests and to earn all he possibly could, more than equalized the higher rate of wages paid in America; and it was much to be desired that the same spirit should prevail in this country. He thought it was possible, however, to adopt, with great advantage, many of the American methods of saving labour; most of all, perhaps, in the handling of the work by electric overhead and other cranes, thereby reducing unskilled labour and securing rapidity of motion. Many older works might also be re-arranged so as to secure continuity in the various workshop-processes; and British bridge-builders would be blind to the signs of the times if they failed to do this. In all probability, however, these changes would be more effectively made now than they would have been some years ago. The danger to British trade for work other than home work would, he feared, remain, unless American methods of designing such work could be adopted. The American bridge-builder was largely the designer as well as the builder, and naturally he standardized his work, thus securing repetition of parts, and leading up to arrangement and adaptation of machinery so as to produce the work most economically. In this, he believed, lay the secret very largely of the success of the Americans as against British manufacturers in foreign and colonial fields.

Mr. Graham. Mr. J. Graham remarked that a perusal of the Paper could not fail to impress the fact that, whatever the American bridge-

manufacturer found to do, he did with all his might. The methods of his British competitor might not at first sight show up well in comparison, and possibly there was a little Eastern apathy on the British side when compared with the energy of the West; but in many respects Great Britain was not far behind, and one thing was certain, viz., that the splendid quality of some of the modern British bridgework erected in various parts of the world could never have been attained by the methods and practice put forward in the Paper. So long as the respective spheres of influence did not clash, it was of little importance that Great Britain preferred to go along in the same old ruts; while nothing but new and go-ahead methods satisfied the feverish haste to comply with American demands. The opinion that in the near future the effect of this greater energy might be felt made the information contained in the Paper of great value, as indicating the direction in which improvements to facilitate rapidity of manufacture should tend. One thing which had seriously handicapped advance in British practice was the fact that there had never been any competition in bridge-design, and consequently the manufacturer had never had any stimulus to develop the simplest and most economical form; while the uncontrolled powers of the designing engineer had enabled him to perpetuate only his individual and often ancient ideas, good, bad or indifferent. Since the introduction of the Warren girder little had been done in British practice to improve ordinary bridge-design, unless it were the insistence on riveted joints in lieu of pin-connections; and it was satisfactory to know that good American practice was tending to confirm this preference. The chief complaint about British bridges was that they were too heavy and in too many parts. It must not be overlooked, however, that the country had been sending bridgework abroad for upwards of 50 years, whereas its competitors had been making for home consumption only; and experience had indicated that short stiff bridge-members were by far the most suitable for the rough handling they had to undergo during export. The modern tendency to send out long, slender, fragile bridge-members often resulted in many of them arriving at the site broken and bent, in consequence of heavy weights having been piled on them in ships' holds. Quite recently painters had called his attention to two of the angle-bars in the bottom boom of a large girder just erected; on examination, apparently slight cracks had turned out to be complete fractures, vastly reducing the strength of the whole bridge. It was apparent, therefore, that light, slender bridges had not

Mr. Graham.

Mr. Graham. everything in their favour, though it must candidly be admitted that their simplicity was very attractive. In the past year, in his experience in India, the parts of a 170-foot span, as delivered from England on the river-banks, had been erected 50 feet from the ground in four days. Within that time a turned service-bolt had been in every drilled hole, and the span had been ready to carry a train if necessary. This had been done without special effort, by native workpeople only; and the result was entirely due to the small number of parts, the simplicity of the connections and the perfection of the workmanship. In the foregoing remarks only the best practice was referred to; there was not the slightest doubt that British bridge-manufacturers were often hampered considerably in having to build bridges to unpractical and amateur designs; and there was yet much to be done before they would be generally employed only on the simplest and best designs, though undoubtedly the tendency was in the right direction. Capricious, arbitrary and useless conditions of manufacture were often imposed unnecessarily; in fact, to undertake some work was almost to court ruin when the low price paid and all the pains and penalties were considered. Manufacturers had only themselves to blame for accepting contracts with absurd and conflicting conditions, but no matter how stringent the conditions might be some one was always found foolish enough to take the work at a low price. A good common-sense bridgework-specification for one and all was extremely desirable, and a conference of engineers and manufacturers would be well employed in drawing up and promulgating such. Assuming that designs were in every way satisfactory, possibly the condition in bridgework-specifications—"all parts of a span to be assembled in position at the makers' works, and all rivet-holes to be filled abroad rimered out *in situ*"—was the one most opposed to American practice. In a recent article[1] he had dealt at some length with this subject, and the conclusion come to had been that the British practice secured the most satisfactory work, and that the holes need not be more than $\frac{1}{32}$ inch larger in diameter than the rivet. At the same time, the American practice was permissible, and the holes might be allowed to be a full $\frac{1}{16}$ inch larger than the rivets, if the shearing-area of the rivets in a connection was 75 per cent. more than the area of the tension member it connected, or the compression member, not including allowance for flexure. However, after designs, conditions and

[1] *The Engineer*, vol. xcii. p. 135.

methods had all been made simple and straightforward, the most vital question was, whether the British workman would approve and help to develop all the contrivances for doing in five minutes work on which he had possibly in the past been paid for one hour's time. One striking passage in the Paper was the statement that an American workman never seemed to want another man to help him to do what he was able to perform himself. This seemed to be the finality of Western advancement, and was the antithesis of Eastern practice. One thing, however, should be impressed on the British workman, and that was that the cheapest and best in every way was now demanded, and that the Empire's requirements should be provided for within the Empire. So far as bridgework was concerned, several years' intimate association with the Indian mechanic had satisfied Mr. Graham that repetition-work, such as the preparation of bridge-parts from templates, was work for which the native was eminently qualified. India was one of the largest consumers of bridgework, and labour being 50 per cent. to 60 per cent. cheaper than British labour, there was not a doubt that, given a yard laid out on American lines, it should never be necessary to go to America for bridgework, if Great Britain was incompetent to provide it at market rates. Nor must it be overlooked that all the objections to the shipment of fragile parts would be overcome if the material arrived in India only as plates and bars instead of as built-up members. Mr. Graham.

Mr. J. J. Robins remarked that for many years the Phœnix Foundry Company, of Derby, had been quick to design specially adapted tools for any multiple work placed in their hands; but, as was well known, British requirements had been so varied in design, that it had been next to impossible to adopt labour-saving appliances unless under exceptional circumstances. A few of these might be enumerated. On the Battersea bridge over the Thames (1889–90) there had been one hundred and eighty-five cast-iron girders to deal with, each girder being in five segments; all these girders had been faced at angles, and finished with the utmost accuracy, by a machine similar to that shown in *Fig. 11*, which was substantially a copy of the Company's design. On the same bed and at the same setting, six holes, 2 inches in diameter, through 3-inch metal, had been drilled simultaneously at each end of the segments, in 30 minutes. This machine had since been used for many purposes, especially for butt-joints of floor-plates for the firm's bridge-building yard. On the Liverpool Overhead Railway, in 1890, the Company had had nearly 11,000 tons of Hobson flooring to deal with, under Sir Douglas Fox and the late Mr. J. H. Greathead. Mr. Robins.

Mr. Robins. For this work a multiple drill of one hundred spindles had been designed and made, which had drilled each side of the flooring at one setting, completing two hundred $\frac{3}{4}$-inch holes in 15 minutes, or eight thousand holes per day of 10 hours; and this machine, before the completion of the work, had drilled upwards of five million holes. With other special tools then in use, it had been closely scrutinized by American experts who had frequently visited the works. Another tool used had been a special bar attached to an ordinary De Bergue punching-press, for punching the T-bars for the flooring. This tool had enabled four thousand $\frac{3}{4}$-inch holes to be punched per day, one man and a boy working it. On the pontoons for the Liverpool landing-stage they had been able to adopt these spaced bars for punching the plates and angles. Goose-necks, such as were represented in *Fig. 7*, had then been in use by them.

Mr. Roechling. Mr. H. A. Roechling remarked that the Author had dealt with a somewhat thorny subject entirely from an engineering point of view. Incidentally he had referred to questions of much wider range, belonging to the domain of national and political economy and social politics, the consideration of which was beyond the scope of the Institution discussions. The question of method was put forward very prominently in the Paper, and he could not help thinking that it was, to some extent, at the root of a few of the difficulties in this country; for there could be no doubt that what was conceived in a perfectly methodical way must, in the end, conquer that which was based on chance and carried out in a disjointed manner, one part of the work not bearing its due relation to others. Political speakers had frequently dwelt upon the absence of proper method in this country, and he thought there was a good deal of truth in the complaint; and while it was not necessary to imitate others who had learned from this country, he thought that, as a matter of sound common sense, there should be no reluctance to profit from the experience of foreign competitors. The Author had very properly placed the labour question in the forefront, for with a limitation of the output and the restriction of the working-hours, British manufacturers were placed at a considerable disadvantage as compared with their competitors who were not hampered in this way. However, he was glad to notice that especially in the engineering trades, the representatives of the labour interest seemed to have become aware of this at last; and he sincerely hoped that before long the strife between capital and labour would cease, and that the workman would realize the disadvantage accruing to him from the restrictions put upon the

manufacturer. The pendulum seemed to have swung too far one way, and it was time it assumed its normal position. The question of free trade was a very large one, but it must suffice to say that signs were not wanting to indicate that the wind was veering round and commencing to blow in the direction of protection. The apostles of free trade would, no doubt, stoutly combat any such tendency; but he felt satisfied that the conditions of the world's markets existing at the time when free trade had been established existed no longer, and, with protection all around, some form of reciprocal dealing with other countries was the only logical sequence. Mr. Roechling.

Mr. S. F. STAPLES thought a few observations on the subject of riveting, as carried out in American works, would be of interest in connection with the Paper. The floating dock which had just been completed for the American Navy Department from the designs of Messrs. Clark and Standfield, by the Maryland Steel Works, and which was the largest floating dock in the world, had been riveted entirely by percussion riveters. The most serious problem which had faced the constructors in the carrying out of this work had been the question of riveting. It had been solved completely by the utilization of unskilled black labourers and pneumatic riveters. The diameter of the rivets varied between $\frac{3}{4}$ inch and 1 inch, and the work had been carried out under most rigid Government inspection. On testing the quality of the riveting it had been found throughout to be most satisfactory, and the dock as a whole has just been tested by easily and successfully lifting with it the largest battleship in the United States Navy. There were upwards of one-and-a-quarter million rivets in this dock, and he believed he was literally correct in stating that not a single rivet in the whole structure has been put in by hand. Almost every type of percussion riveter had been used in carrying out the work. For riveting up frames which were attached to the skin, ordinary yoke machines had been used; for riveting the skin-plating, pneumatic and lever-bar holders-up had been used, and for driving the 1-inch rivets which were to attach the joint-plates connecting the different parts of the dock together to the body of the dock, special heavy dollies had been used. Upon the strength and water-tightness of these latter connections the safety of the whole dock depended, but there had not been the slightest difficulty in getting perfectly sound riveting. On straightforward work as many as 1,460 rivets had been put in by one gang in 1 day of 10 hours, the rate of payment for this class of work being 75 cents for one hundred rivets. From experience gained in his own works upon the same Mr. Staples.

Mr. Staples. class of construction, he knew that it would have cost about two and a half times as much, and the amount of work turned out would not have been anything like as large, thanks to trades-union restrictions. This, surely, was a striking example of what would have to be done in this country if British manufacturers were not to be left behind by their competitors. Some years back he had had to make about ½ mile of large wrought-iron water-pipes, and these he had had entirely machine-riveted by unskilled labour, very successfully. At the end of the time he had been found out by the union, and had been informed that if he attempted to repeat the performance all the union men in the shop would be called out, notwithstanding the fact that he had practically demonstrated that the work could just as well be done by labourers as by members of the union who were skilled riveters. He thought many engineers would agree that the time was not very far off when there would be another big fight with the unions, in which the central question would be whether machine-riveting should or should not be done by any man who had sufficient intelligence to handle a machine, whether he had been regularly apprenticed or not, whether he belonged to a union, or whether he preferred to be a free man, paid according to his own energy, skill and intelligence.

Mr. Thorpe. Mr. W. H. THORPE considered that the particulars supplied with reference to the drawing-office output were of interest, but thought such figures were of little value unless a distinct knowledge existed of the way in which the total tonnage was made up, whether the bulk was special or "repeat" work. He thought it might be of service to give some results of his own experience relating to bridges of which in each case one only had been made, and detailed in the manner usually considered complete in this country (with quantities), including a swing-bridge, a swing-aqueduct, three N-truss bridges of 102 feet, 150 feet, and 219 feet span, and a plate-girder bridge; making a total of 1,800 tons, which worked out at 1,100 tons per year of 49 weeks, having 40 hours each. There was, however, no true comparison to be made between the output of works drawing-offices, in which much incidental work was done apart from that strictly relating to the final product, and the work of an engineer's office dealing only with design. With respect to works cost, it certainly appeared from the particulars given that this must be materially less than for English bridge-yards, and it would be of value if some further details were given: failing that, perhaps the Author would state whether 25s. to 30s. per ton was about the figure, as would seem to be the case. Low

shop-cost was greatly favoured by the large use made by American bridge-engineers of channel and H sections. He thought it inexplicable that in England engineers should still use channel sections built up of a plate and two angle-bars, when the solid bar of equal weight was stronger, cheaper, and neater. Much of the time lost in completing contracts was due to waiting for steel from the mills, a difficulty which was accentuated by the fact that quite commonly four to six makers supplied steel for the same job. This necessitated visiting each steelmaker's works for the purpose of testing; by the time an inspector (not being resident) reached some of these, it became quite a business to find the plates or bars he had to deal with, which might be covered by many tons of later-rolled material, also awaiting an inspector. To accept the test-pieces preserved by the maker for his own use, reduced the whole process to a farce, as it would clearly be quite as reasonable, and more economical, to accept the maker's own tests. He was disposed to think it would be of advantage to all concerned if official inspectors were appointed by, say, the Board of Trade, to be stationed at the mills in order to test all material as rolled, and to be prepared on the results of such tests, to issue certificates at a scale of fees to be decided. He thought this might be done, still retaining the engineer's right to make his own tests, if he preferred to do so. Much time would be saved, as the material, having been tested on leaving the mill, would be loaded up without unnecessary delay, if the certificate showed compliance with the specification. While it was evident that much might be learned from American experience, it need not be forgotten that this was not in all respects enviable, and that it would be well to avoid such a straining after economy as to favour results in any degree similar to those culled from the pages of the *Railway Review* (Chicago) for the years indicated below, which, though possibly not complete, sufficiently justified the warning. It might be admitted that the cases cited were, to a large extent, irrelevant to the discussion, relating as many did to timber bridges; but only those distinctly Mr. Thorpe.

	Total Failures and Washaways.	Metal Bridges.
1896	93	6
1897	27	3
1898	3	0
1899	5	1
1900	76	2
1901	34	10
	238	22

Mr. Thorpe. stated to be metal had been placed in that category. The majority had been washed away by floods; bridges destroyed by fire, or by loads extending beyond the gauge, had not been counted. From the total number of bridge-accidents, forty-three fatalities in all had resulted. Of the failures of metal bridges about half a dozen were "collapses."

Mr. Wilson. Mr. JOSEPH M. WILSON remarked that the subject of the Paper was naturally of greater interest to the British than to the American manufacturer, in that its object was to suggest to the former how he might recover lost ground over his rival in the business in question. The Author appeared to state the situation very clearly, and his selection of Pencoyd as an example of a modern American bridge-plant was a happy one, as that was probably the largest and best example at the present time in the United States, and was the principal shop of the lately organized American Bridge Company. He could add little or nothing to the Author's excellent description, although he was more or less familiar with the plant, and had known for years most of those who operated it, having had a large amount of work done there. The pith of the whole matter lay in a thorough system and organization down to every detail, from the inception of the work in the drawing-office to its complete erection in the field; with competent, energetic men in every department, thoroughly familiar with their duties, full of vim, with eyes open to the adoption of every expedient to facilitate the work, either in time or economy of cost, and having a thorough personal interest in its success. The Author's reference to the maintenance of the full efficiency of the shop by the replacement of machinery, when it became in the least obsolete, with new, up-to-date machines, was one of moment. The use of standard types of bridges exactly suited to the operations of the works, or rather, the adoption of standard types and the adaptation of the works to their construction, was very important. Standard designs and specifications were used, as well as standards for details, standard rules for making shop-drawings, points to be observed in order to facilitate erection, etc.; and these were printed in book form for bridges, office-buildings, warehouses and factories, and were distributed gratuitously to engineers and architects, so that all designs for work might be adapted to the special machinery and operations of the Company's plant, thereby facilitating in every way the economical construction and rapid completion of any order. The standardization of shapes was in direct line with the development of the system of interchangeable parts and the use of tolerance gauges, which demanded that these

parts should be made by machinery and not by hand, and which had done so much in America for its machine manufacture and in one sense was now doing it on a large scale for its bridgework. While this idea had originated in France nearly 100 years ago, it had soon been abandoned from not having been started in the right direction. The United States had been the first nation to originate the proper method of doing such work, and it had carried out the system for 50 years before any other country had followed its example. Mr. Wilson.

The AUTHOR, in reply to the Correspondence, remarked that, with regard to the drawing-office arrangements referred to by Mr. Buchanan, it appeared to him that the work of drawing out the details of a complicated joint or ascertaining the exact length of a bridge-member should be done in the drawing-office, where the draughtsman has his drawing-board and instruments, works of reference, and a comparatively quiet and clean place to work in, rather than (as was frequently the case) in the template-shop, with a steel rule, a square of uncertain accuracy, a pair of templater's compasses, a chalked board, and a carpenter's pencil; among all the noise, dirt, and interruption of a template-shop. In other words, it paid to have draughtsmen's work done in the drawing-office, and not in the template-shop. He did not quite agree with Mr. Graham that American methods were incompatible with good quality in the work, his own experience leading him to believe that good work could be done just as cheaply and as quickly as bad work, and that rapid progress could be made only when the work was good. The delays and alterations necessary when work fitted badly, more than compensated for any apparent cheapness in bad work. He could fully endorse Mr. Graham's remarks regarding the facility with which first-class British work could be erected. During the Afghan War, 20 years ago, the Government of India had been so desirous to get the Sohan Bridge, near Rawal Pindi, completed, that they had issued instructions to him to the effect that they were willing to risk the loss of a span rather than delay the work. Floods had been of almost daily occurrence, and the staging, which had been over 100 feet in height, had already been washed away once; but the last span of 120-foot close-latticed girders had been made self-supporting in 26 hours, the bottom boom being fully riveted up and the rest of the span bolted. The labour had been entirely native labour, under European supervision. He could also fully corroborate Mr. Graham's observations in regard to the Indian mechanic. Excellent girders of The Author.

The Author. considerable span had been built both in Bombay and Calcutta, and about 14 years ago he had attempted, in vain, to obtain permission for a large firm in Bombay to tender for steelwork for the State railways, to be constructed in Bombay with material imported from England. Had this permission been obtained there would have been a large development of steel construction in India. He regretted that he was unable to furnish the information asked for by Mr. Thorpe as to works cost per ton. With regard to the "collapses" of metal bridges, many of the earlier bridges in the United States were, to use the mildest term, "peculiar," both in design and workmanship. Wheel-loads had largely increased since the time of their construction, and the wonder was that there had not been more collapses. Modern bridges in the United States were no more likely to collapse than were those in Great Britain.

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21 January, 1902.

CHARLES HAWKSLEY, President, in the Chair.

The discussion upon the Paper by Mr. H. B. Molesworth, on "American Workshop Methods in Steel Construction," occupied the evening.

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28 January, 1902.

CHARLES HAWKSLEY, President,
in the Chair.

(*Paper No. 3232.*)

"The Sewerage Systems of Sydney, N.S.W., and its Suburbs."

By Joseph Davis, M. Inst. C.E.

Sydney, the capital of New South Wales, is situated on the shores of the land-locked harbour of Port Jackson, which has a coast-line of about 170 miles, and is practically all deep water. The population of the city is 98,250, and that of the suburbs 328,700, making a total of 426,950 distributed over an area of 140 square miles. Since 1840 the population has trebled. In 1898 the capital value of rateable property in the municipalities was £86,927,600, and the annual value £4,965,400.

It is satisfactory that in the rush of material progress sanitary precautions have not been overlooked, and Sydney to-day enjoys the advantage of a well-considered and effective sewerage system. The works described in this Paper were commenced in 1880, and are now, under the Author's supervision, nearing their completion. They have involved a capital outlay of over £3,300,000, and the great sanitary improvement effected by them has fully justified the expenditure. The general death-rate, which was 26·77 per thousand in 1875, before the new sewers were brought into use, has fallen consistently as the sewered area has increased, until, according to the latest returns, it was 13 per thousand. The reduction in mortality, from zymotic diseases particularly, is shown in the Appendix, Tables II, IIa, and IIb.

Although the physical conditions favour a rapid drainage of surface-water, dealing with the sewage was rendered unusually difficult owing to the whole area consisting of ridges and valleys. Generally speaking, however, the district is divided by a main ridge running east and west. The north and south slopes drain respectively to Port Jackson and to Botany Bay. The main ridge attains to a height of over 300 feet above sea-level in parts of

Waverley, the average height of the greater part of the high land in the eastern suburbs being about 200 feet; and the spurs from the main ridge between the several bays of Port Jackson slope gently until they approach the harbour, where they fall, in places very precipitously. The natural water-courses in the valleys intervening have good slopes until they approach the foreshores.

Geologically considered, the district is underlaid by the Hawkesbury series, consisting of parallel beds of sandstone, interstratified with occasional bands of shale. The sandstone dips westward of the city, and in this locality the Wiannamatta shales appear over it. The coal-measures lie under the sandstone, being nearly 3,000 feet below the surface. Basaltic dykes running east and west are met with, and in places the sandstone is capped with drift sand.

The first settlement in Australia was established by Governor Phillip, in 1788, upon the shores of Sydney Cove. A brook of pure fresh water entered the harbour at this bay, which is now Circular Quay, and this was the chief reason why the site was adopted for the township that slowly grew along its banks. In 1791 tanks or wells were excavated in its rocky bed, and the brook from this circumstance took the name of "Tank Stream." From this source the water-supply was derived for many years, but in spite of most drastic regulations the stream became contaminated in time, and degenerated into the main drain of the town.

In 1827 a tunnel was cut through the main ridge for the purpose of bringing water from the Lachlan Swamps, situated about 2 miles south-east of the settlement. This tunnel, known from the name of its designer as "Busby's bore," continued to serve the town for more than 50 years. The supply was afterwards increased by the erection of a pumping-station at Botany, which tapped the same watershed at a lower level, but the insufficiency of this source, as well as its liability to pollution, led, about the year 1880, to the initiation of the Nepean River scheme, which may be briefly outlined.

About 50 miles to the south-west of Sydney the head-waters of the Nepean River and two of its tributaries in the coastal ranges are diverted, and the water gravitates through 40 miles of aqueducts, canals, and tunnels to a large storage reservoir constructed in a natural basin at Prospect, 23 miles from the city. The reservoir has a surface-area of 1,261 acres when full, and a total capacity of over 10,000,000,000 gallons, half of which is available for gravitation to Sydney through large iron mains. The average daily supply has increased from 8,144,169 gallons in 1888 to 18,283,000 gallons in 1898, when a population of 434,810 was

served, including outlying towns. The daily average supply per head increased in the same time from 27·49 to 42 gallons.

The Old Sewers.—Sydney was incorporated in 1842, but in 1853 municipal mismanagement led the Legislative Council to repeal the Incorporating Act, and to place the control in the hands of three City Commissioners, who initiated what is now known as the "Old System of Sewerage." The work was continued by the Municipal Council, which was restored in 1855, and in 1877 there were 33 miles of sewers in operation, which drained 1,200 acres, or the whole of the thickly-populated harbour slopes of the city. These sewers, built of considerable size in brick and stone, were designed to remove street surface-waters as well as sewage, and discharged directly into the harbour. There were twenty-five of these outlets on the water frontage. The following are particulars of the largest five sewers:—

1. Woolloomooloo sewer, stone, 10 feet by 6 feet, segmental.
2. Fort Macquarie sewer, brick, 6 feet, oviform.
3. Tank Stream sewer, stone invert, brick sides and arch 10 feet wide.
4. Hay Street sewer, stone, 10 feet by 8 feet, horse-shoe section.
5. Blackwattle swamp sewer, brick, 6 feet, oviform.

The natural slopes were followed, and therefore the gradients on the higher ground were steep, and on the lower lengths flat. In 1875 there were about seven thousand water-closets connected with these sewers, but the connections in many cases were very defective.

The Tank Stream sewer, running through the centre of the city and completely built over, was in a foul and dilapidated state, the sewage stagnating along the uneven invert, while the bad air escaped anywhere it could. With this exception, in regard to structure the sewers were, on the whole, fairly sound, but the system of discharging at the harbour frontages was not satisfactory. In this year the sanitary arrangements of the city were so defective that the Government appointed a Sewage and Health Board, consisting of the highest professional experts available, to report comprehensively upon the question. In its reports of progress during the ensuing two years this Board threw light upon several glaring evils, and measures were taken to remedy them; but it was recognised that the only real security lay in a comprehensive sewerage system, which would divert foul waste from the harbour. A scheme was accordingly submitted with the Board's final report in 1877. On the basis of these proposals, generally speaking, the two systems serving the city have been constructed.

The Board divided the city, with the nearest suburbs, containing in 1877 a population of about 160,000, into two drainage-areas,

corresponding to the watersheds falling towards Port Jackson and Botany Bay respectively. The northern system, including the great bulk of the population on the harbour slopes, it was decided to intercept by a sewer running east, through the northern spurs of the main ridge, and discharging into the ocean, 4 miles from the city, near Bondi. The southern system it was decided to drain by a sewer running south with the southern slope of the main ridge, and across a stretch of flat country to discharge on a sewage-farm at Shea's Creek near Botany Bay. While all the dry-weather flow was to be intercepted from the old sewers, it was decided to still use them as storm-water conduits and as storm overflows for the new sewers.

It was estimated that the probable cost of the new scheme, including branches, would be, for the northern system £256,000, and for the southern system £131,000—a total of £387,000. The "partially combined" system was, under the conditions existing, decided upon, and the sewers were to be designed to discharge the following allowances of sewage and rainfall per day:—

——	Sewage.	Rainfall over area.
Northern division	75 gallons per head	½ inch for city area.
Southern „	75 gallons per head	1 inch.

Between 1872 and 1876 the death-rate in the city had increased from 22·69 to 26·77 per thousand, and in the suburbs from 14·48 to 22·62, and the need, therefore, for improved sanitation became so urgent that with a view to immediate action the Government in 1877 instructed the late Mr. William Clark, M. Inst. C.E., to report upon the Sewage and Health Board's scheme. In June of the same year Mr. Clark reported and practically endorsed the proposals.[1] By slightly lowering, however, the ocean outlet of the proposed northern main sewer at Bondi to 8 feet above mean high-water level, Mr. Clark showed that it would be possible, without exposing the outlet to any danger through wave-action, to secure a better slope, viz., 3 feet 6 inches per mile, and at the same time to lower the proposed level at the city end of the sewer and allow of its future extension to serve a much larger area, including parts of the western suburbs. Mr. Clark, in the absence of full information, did not revise the scheme for the southern system in detail, but made certain recommendations, which will be stated later.

[1] "Report to the Government of New South Wales on the Interception and Disposal of the Drainage of the City of Sydney and Suburbs." Sydney, 1877.

The scheme thus revised having received the approval of the authorities, the necessary funds were voted by Parliament, and the works were commenced in 1880 under the direction of the late Mr. W. C. Bennett, M. Inst. C.E., and subsequently of Mr. R. R. P. Hickson, M. Inst. C.E.

When the northern and southern systems were nearly completed, and the main sewers and some of the reticulation lines were already in use, the necessity arose for an administrative authority, and accordingly the maintenance of the sewers was by Act of Parliament vested in the Board of Water-Supply and Sewerage. On this Board both the Government and the Municipalities are represented, the former as the authority incurring the large initial expense involved, and the latter by virtue of their being called upon to pay the annual charges of maintenance, interest, and repayment.

In addition to the northern and southern systems, a third system was necessitated by the expansion of the western suburbs. This proposal was prepared in 1888, and the works comprised therein are now practically completed. They provide for a drainage-area of 22 square miles and an ultimate population of 400,000, and include the treatment of the sewage by intermittent downward filtration on an area adjoining that in use for the southern system at Botany, Fig. 1, Plate 2.

Outside the northern, southern and western systems, there are several suburbs for which separate schemes have been devised. On the north shore of the harbour, opposite the city, an area including North Sydney and Mosman, containing about 2,500 acres, has been provided for by gravitation sewers, the sewage being treated by precipitation, and intermittent downward filtration through sand. The elevated residential suburbs of Chatswood and Willoughby, 6 miles north-west of the city, are being sewered on the separate system, and the sewage is to be treated by septic tanks and bacterial filters. Manly, a favourite watering-place, with a population of 3,000, 7 miles from the city and near the entrance of Port Jackson, has been provided with a gravitation system having an ocean outfall. At Parramatta, a town of 13,000 inhabitants, 14 miles west of Sydney, at the head of an estuary of Port Jackson, a pumping-scheme has been prepared, and includes the treatment of the sewage by septic tanks and filters.

The cost of the sewerage of Sydney and suburbs is shown in the Appendix (Table I.). The capital cost has been £3,356,907. There are 390 miles of sewers actually in use, serving a population

of 281,000, but the latter figure is increasing rapidly now that the sewers are available. The capital cost of the works when completed will, it is estimated, be £4,115,713, and the prospective population to be provided for is estimated at about 1,200,000.

The Northern System.—The area drained by the northern gravitation system, and having its outlet to the ocean through the Bondi sewer, comprises the whole of the watershed towards Port Jackson, and has a total extent of 7,769 acres. It includes the greater part of the city and the suburbs on the northern slopes from Waverley on the east to Balmain on the west, and contains a population of 200,000. The total number served by the system at present is about 165,000, but this figure will be greatly augmented when the extensive reticulation works now in hand are completed, and when the low-level zones along the harbour foreshores are connected.

Except where a few short depressions are crossed, the sewers are all below the surface, the tunnels being generally through solid sandstone. An oviform cross section has been adopted, and the material generally used was concrete, gauged 4, 2, 1, of basalt or bluestone broken to a 1½-inch gauge, sharp sand and Portland cement. Where the sewer was in tunnel, radiated double-pressed bricks were used in the formation of the arch, and the concrete invert and sides were everywhere rendered with 1 to 2 cement mortar. The leading particulars of the northern system are given in the Appendix, Tables III. and IV.

The Bondi Outlet.—The main sewer discharges into the ocean on the face of an abrupt cliff near Ben Buckler Head, where the coast is very rugged and indented, Fig. 2, Plate 3. An accurate survey and observations of the set of the currents in the vicinity were made in the first instance, when it was found that the floats drifted northward and seaward at first, and then returned past the foot of the cliff southward. Now that the sewage is discharged into the sea, it leaves the mouth of the sewer in a south-easterly direction, denoting its presence by a black stream, widening until it gets about half a mile from the outlet, when it disappears. The observations, therefore, were not altogether reliable, possibly through the influence of the wind on the floats being greater than that of the currents.

With easterly gales, waves of great height and violence break on the cliffs at the spot, and the outlet had to be so designed as to prevent any destructive action on the sewer. It was ultimately decided to dispense with valves or other mechanical devices which would be liable to get out of repair or be destroyed,

and to adopt the arrangement illustrated in Fig. 3, Plate 3. At 200 feet back from the face of the cliff a large chamber 30 feet in length in the line of the sewer, 24 feet wide and 31 feet in height, was formed in the sandstone rock at the bottom of a 12 feet by 5 feet ventilating shaft. The sewer, 8 feet 6 inches by 7 feet 6 inches in cross section, enters this chamber with an ogee drop of 3 feet 6 inches. The level of the sewer at the top of this ogee is 7 feet 1½ inch above mean high-water level. Across the chamber is a massive weir of concrete faced with basalt, roughly triangular in plan, with its apex pointing upstream, and forming a tongue or cut-water. The stream of sewage divided by this cut-water runs round both sides of the chamber, passing, on each side, by a 4-foot circular opening through the weir to the lower half of the chamber. Thence it discharges through either or both of two 4-foot circular outlets, which are lined with basalt and run down from the chamber to the sea, making an angle of 31° with each other, and each having a gradient of 1 in 39. These outlets are at such angles to the coast that even under the severest circumstances one outlet is free from any inrush of waves, and provides an exit for the sewage. A heavy sea rushing up either outlet is repelled by the face of the weir in the chamber without causing any shock to the main sewer above. The only effect of such an inrush is to check the flow for an instant, and to cause a slight rise behind the weir till the wave falling back down the outlet tunnel draws the sewage quickly after it. The weir is carried only to the level of three-fourths of the height of the main sewer, so that in the very remote contingency of the openings through the weir becoming blocked by floating débris, the sewage will pass over the top of the weir. An iron ladder in the shaft gives access to the chamber; and the shaft is continued above the surface as a ventilating-tower.

Between 20 chains and 80 chains from the outfall, the 8-foot 6-inch by 7-foot 6-inch sewer had to be carried through the wet drift sand which fills a dip in the rock between Rose Bay and Bondi. The cuttings were generally over 30 feet deep, and were sheathed throughout with permanent hardwood sheet-piling. Between these timbers the concrete sewer was formed, the thickness ranging up to 4 feet at the invert and sides, and 3 feet at the top. A cross section of the sewer at this point, which in places was built on heavy hardwood decking, is shown in Fig. 4. The tunnels also required heavy roof- and side-timbers, and percolating water gave great trouble, necessitating as many as nine centrifugal pumps being kept at work. The city inter-

cepting-sewers join the outlet length at Liverpool Street. At this point a large junction-chamber, which is typical of those usually adopted, was built (Fig. 5, Plate 3).

Passing through the city, the sewer is carried under the low ground along George Street West by means of a cast-iron inverted siphon 1,353 feet in length, consisting of 3-foot 9-inch pipes. At the upstream end, near Bay Street, an overflow-weir is formed, and is connected with a covered channel leading to the harbour to relieve the sewer above of any heavy storm-water flow. The siphon passes along the street at a minimum depth of 9 feet below the surface. At the lowest point it crosses a storm-water culvert discharging to Blackwattle Bay, after which it rises with the slope of the street to the outlet-well, where there is sufficient cover for the sewer to resume its ordinary form. As the invert of the outgoing sewer is 1·34 foot below that of the upper one, the siphon discharges even during a minimum flow with a head of about 18 inches. Under ordinary conditions, by temporarily impounding the sewage at the inlet-well, a sufficient head is obtained to disengage deposited matters, but when thorough scouring is required the siphon is emptied. This is done by opening a penstock in an 8-foot covered iron scour-well, 13 feet below the incoming sewer, at the lowest point. The sewage and flushing-water drawn off passes through a pipe to the low-level pumping-station at Blackwattle Bay, and is there lifted to the main sewer at a point on the lower side of the siphon.

Towards Balmain the main line crosses the valleys of Johnstone's and White's Creeks, over which the sewer, 4 feet 3 inches by 3 feet 3 inches and 4 feet 6 inches by 3 feet 6 inches respectively, is carried by two aqueducts having a combined length of about 25 chains (Fig. 6). The arches are of concrete built on the Monier principle, having each a span of 82 feet 10 inches and a rise of 9 feet 6 inches, and springing from concrete piers. The thickness between the sewer-invert and the soffit of the arch is only 15 inches, the arch being 12 inches thick at the crown and 14 inches at the abutments, while the sides of the concrete trough forming the sewer are only 4½ inches thick. The concrete over the piers and in the spandrels is cut out in the form of jack arches (Fig. 6), giving the aqueducts a light and graceful appearance; while, as tests have shown, the economy of material allowed by the adoption of the Monier principle is accompanied by a greater degree of strength than in an ordinary brick arch. The disposition of the iron rods inserted in the Monier work is illustrated in Fig. 7.

To prevent surcharging, there are five storm-overflows on the main sewer, where the latter crosses the storm-water channels constructed along natural water-courses. The Deep Dene overflow-channel is a closed oviform conduit carried on concrete arches of 25 feet span over the swampy ground at Rushcutter's Bay. The piers were built of concrete blocks resting on circular foundation-wells carried down to the firmer substrata. These wells, 10 feet in diameter, were formed of brick rings filled with concrete or sand.

Sections through the arches, and also details of the outlet of this channel to the tidal waters of Rushcutter's Bay, are shown in Figs. 8, Plate 3. The outlet of the channel is provided with a tidal flap, and a low-level opening through which the ordinary dry-weather flow is discharged into deep water.

Where the old sewers in the city are intercepted, the use of jumping-weirs has been resorted to, any excessive flow due to storms being allowed to run to the harbour.

The Southern System.—The area drained by the southern system comprises 1,306 acres, and contains a population of about 62,000. It includes parts of the City, Paddington, Redfern, Newtown, Macdonaldtown, Alexandria, and Waterloo. The outfall sewer discharges at the Botany Sewage-Farm at the mouth of Cook's River, where the sewage is treated by intermittent downward filtration.

The southern slope of the main Sydney ridge is much more gradual than that on the northern or harbour side, and the outfall sewer, after falling with the slope southward, is carried over a long stretch of low-level sandy ground before reaching the site of disposal at Botany. The drainage-area, or the populous centre, is some distance from the sewage-farm. The natural outlet for surface-waters is Shea's Creek, which, rising in Redfern, runs south over the level country and discharges into Cook's River near Botany Bay. When the city and its suburbs spread in this direction, prior to the establishment of the present sewerage system, this creek and its tributaries received a great portion of the foul waters from the street-gutters. In the hot weather the flow in the natural channels was very slight, and the insanitary state of the suburbs adjacent thereto was one of the first matters to claim the attention of the Sewage and Health Board appointed in 1875.

In their report of 1877 the Board, after dismissing as impracticable a proposal to connect the southern slopes with the northern or Bondi outfall, recommended that a system of pipe-sewers

should be constructed along the valleys at Redfern and the southern part of the city, and that these pipes should be intercepted by a 5-foot circular outfall-sewer running south and discharging on to a sewage-farm at Shea's Creek near Botany. Here it was proposed to resume about 100 acres of waste swampy ground, to be drained and prepared for intermittent downward filtration works. The sewer was to be kept high enough at its outfall to allow of being carried farther south to an alternative site of disposal (afterwards adopted) at Botany.

As in the case of the northern area, the Board advised the adoption of the partially combined system, and concluded that the sewers should be designed on the following basis:—

Drainage-area	1,037 acres.
Prospective density of population .	47 per acre.
Sewage or dry-weather flow . . .	75 gallons per head per day.
Rainfall to be removed	1 inch per day.

The dry-weather flow was the same as that assumed for the northern system, being based on a prospective water-supply of 75 gallons per head per day, a rate much beyond that obtaining with the imperfect water-supply at the time, but one which it was reasonably expected would be reached when the Nepean River scheme, then foreshadowed, was brought into operation. The allowance made for rainfall was double that for the northern system, as on the southern area the natural fall was very slight, and there was no such direct run off as existed on the steeper and shorter harbour slopes.

Mr. Clark, in revising the scheme, recommended that the sewers should be designed to carry off a slightly larger rainfall, viz., 1·2 inch per day, pointing out that although a fall of more than 1 inch in 24 hours had only occurred, on an average, thirteen times a year for 19 years, the heavy downpours occasionally recorded demanded an even more liberal allowance in the sewers than had been made. Mr. Clark also advised that the sewage-farm should from the outset be located at the farthest site proposed—Botany Bay—and these alterations were adopted.

The scheme was designed originally to serve a maximum prospective population of 48,000, the cost being estimated at £211,000. As now completed the system has cost about £360,000, and serves a closely-built drainage-area of 1,306 acres, carrying a population of 62,000. The scope originally anticipated has therefore been extended, but it is satisfactory to note that, owing to the liberal allowance made for dry-weather flow (12 cubic feet per head per

day), the sewers have been able to cope with all demands upon them, even with the combined rainfall and sewage flow during storms of exceptional intensity.

From a sanitary standpoint the system, supplemented by the conversion of the natural water-courses into properly formed concrete storm-channels, has completely transformed the southern part of the metropolis. In Waterloo, where the low sandy area was formerly very water-charged, the level of the subsoil-water has been lowered by means of subducts; and in this suburb the death-rate from phthisis has been reduced in seven years from 15·9 to 6·4 per 10,000. In Redfern the rate fell in the same time from 12·1 to 5·2 per 10,000. These and similar improvements in regard to other preventable diseases and the mortality rates generally have been reported, from year to year, by the Board of Water-Supply and Sewerage.

The main sewer starts at the summit of the watershed in Paddington as a stoneware pipe, and crosses thence to Bourke Street in the city, where it assumes an oviform section in brick-work and concrete. Along Bourke Street it passes with the slope southward, increasing in size from 3 feet by 2 feet to 3 feet 3 inches by 2 feet 2 inches, with fairly sharp gradients. Here it was laid alternately in open cutting and in tunnel through sand or clay, the sand near the lower levels being very water-charged, so that substantial cross sections of concrete were necessary, and subducts of glazed stoneware pipes had to be laid under the sewer. Near Botany Road in Waterloo the size changes to 4 feet 6 inches by 3 feet 6 inches, the gradient here being 1 in 266. At Botany Road the outfall-sewer proper commences. It is of circular cross section and 5 feet 6 inches in diameter. It runs southward through Waterloo and Botany, and after a course of 2½ miles reaches the inlet house near the Botany sewage-farm. It has a fall of 1 in 1,320, passing over the flat low-lying districts, where it is covered in embankment. No special difficulties were met with, and the sewer was substantially built of bluestone concrete, lined with 4½ inches of brickwork to the springing-level. The arch is formed in brickwork, 9½ inches thick. The inside is rendered throughout with 1 to 2 cement mortar. The concrete base is square in cross section, and rests either directly on the sand or on a layer of quarry rubble. In some places a deep foundation of sandstone concrete was necessary. Some small watercourses are spanned by concrete arches, and at such crossings the sewer is provided with sluice-gates and offlets for scouring purposes as well as with storm overflows.

The drainage of Redfern and Waterloo North is intercepted by two branch sewers, consisting of 24-inch and 18-inch pipes.

When the western suburbs system was designed in 1888, it was decided to drain into the southern outfall a portion of Macdonaldtown and Alexandria, and this is now effected by a 2-foot 6-inch circular sewer, which crosses the valley of Shea's Creek in the form of an aqueduct 1,200 feet in length, consisting of a riveted wrought-iron tube fitted with expansion-joints and supported by ashlar masonry piers 50 feet apart.

The sewage-farm (Fig. 1, Plate 2) is on the south side of Cook's River, where the latter enters Botany Bay. It comprises 310 acres on a tongue of land lying between the river and the bay. The surface is fairly level, with a general elevation of 5 feet or 6 feet above high-water level, and the formation is a fine drift sand underlain by clay, and is very suitable for filtration purposes. The site has been in use for over 12 years, and although at first the dry barren sand was not promising from a "farming" standpoint, the constant application of sewage and the ploughing in of sludge has converted the surface to a good loam, from which very successful crops of lucerne, rye, sorghum, cabbages and other produce have been grown. These crops are either sold or more profitably used as fodder for pigs, of which large numbers are reared for sale. The agistment of stock also forms a source of revenue, and the farm, which is ably managed by the Water and Sewerage Board, bids fair in time to pay its own way. Although there is a growing population at Botany near the farm no nuisance or danger has arisen from the operations, the success of which has thoroughly disposed of merely sentimental objections.

On the north bank of Cook's River, opposite the farm, the outfall-sewer ends at an inlet-house, from which the sewage, after screening and precipitation, passes over to the farm through an inverted siphon of cast-iron pipes laid under the river-bed. On the farm side the siphon ends in a concrete outlet-well, and the sewage rising therefrom overflows into an open concrete main carrier, from which it is distributed to filtration-areas which are arranged on either side. The inlet-house is a single-storied rectangular brick building 74 feet by 37 feet. In the foundations, which are of concrete, are formed the straining-tanks, overflow-channels and settling-pit. These are all open inside the building, and are worked from gangways. The sewage in the first place enters a receiving-well, from which it can be admitted through penstock-openings into either of the two straining-tanks, which are used alternately, and in each of which there

are three circular iron screens 12 feet 6 inches in diameter. The bars of the first screen are 4 inches apart, those of the second 2 inches, and those of the third 1 inch, and the three screens in each tank are worked by means of hand-gearing from one end of the tank, which enables them to be revolved and raised for cleaning when necessary. The sewage, freed from floating débris, enters an annular settling-pit surrounding the inlet-well of the siphon. Lime is added to assist precipitation, and the clearer top liquid overflowing into the siphon is conveyed through it to the farm across Cook's River. The sludge is removed from time to time by a grab worked by a 2-HP. oil-engine, and is discharged through shoots into trucks outside the building. It is then drawn by a small locomotive over a bridge spanning the river to the farm, where it is spread out and ploughed into the sand as a fertilizer.

The siphon, consisting of 3-foot 9-inch circular cast-iron pipes, is 1,090 feet in length, and was laid in excavation in the silt and stiff clay of the river-bed. Coffer-dams formed of hardwood piles driven closely together and caulked were used in this work, and the pipes after jointing were bedded in and surrounded with bluestone concrete between two rows of permanent hardwood sheet piling, which was driven through the clay to the shale substrata.

The outlet-well of the siphon is of concrete, and is covered by a small building or outlet-house. The sewage rising in this well is taken off by the main carrier through the farm. A scour-channel leading from the well to Cook's River, and commanded by a sluice-valve, provides a means of effectually flushing the siphon. To relieve the latter of any excessive storm-water flow, an overflow channel runs round the straining-tanks in the inlet-house, discharging into the river. The average daily discharges of the outfall sewer for seven years, with the amounts of sludge removed from the inlet-house, are shown in the Appendix, Table V. The discharges, depths of flow, and velocity obtaining in the southern outfall sewer, are given in Table VI.; while Table VII. contains particulars regarding the southern system of main sewers.

The Western System.—Between the years 1871 and 1891 the suburban population of Sydney increased from 63,020 to 275,717. The greater part of this rapid increase occurred in the western suburbs, and in 1888 it became necessary to decide upon a sewerage scheme for this district, which comprises an area of 22 square miles, draining naturally to Parramatta River on the north and to Cook's River on the south. Generally the surface is fairly high, being at the more elevated parts 160 feet above mean high-water

level. Undulating ironstone and clay ridges alternate with the valleys of numerous small creeks.

As no law existed formerly to restrain building on insanitary sites or "made ground," it is not surprising that the low-lying areas nearest the city became overcrowded, and, in the warm weather, were veritable hotbeds of typhoid fever. Before 1885 the suburbs had a lower rate of mortality than the city, but as the latter began to enjoy the benefit of better sanitary measures, the position was decidedly reversed, and certain of the western suburbs in particular earned a most unhealthy record. It became incumbent on the Department of Public Works to face this serious development, and in 1888 Mr. G. H. Stayton, M. Inst. C.E., at that time one of its officers, was instructed to report upon the subject, and to submit a sewerage scheme for the western suburbs. Works were proposed which were estimated to cost £1,817,896. In 1889 the scheme was approved by the Parliamentary Standing Committee on Public Works, and that body recommended that the first instalment of the main sewers, the cost of which was estimated at £830,304, should be commenced immediately.

For the purposes of sewerage it was necessary to divide the districts, in which a variety of conditions prevailed. The northern and southern divisions lying nearest the city have, in accordance with the scheme, been intercepted by extensions of the northern and southern systems. They have, therefore, been considered in connection with these systems which have their outfalls respectively at Bondi and at the Botany sewage-farm.

The western division, comprising the great bulk of the suburbs concerned, has a separate outfall at the west side of the Botany sewage-farm (Fig. 1, Plate 2), and ranks in sequence of time as the third main system of Sydney. The area and population allowances were the following:—

Area in Acres.	Assumed Ultimate Density. Persons per Acre.	Total Prospective Population.
10,632	33·065	351,545

The high rate of increase already mentioned as obtaining in the population of the western suburbs during the 20 years preceding the design of the scheme in 1888, has been greatly modified since 1890. For some years previous to 1888, the population increased at the rate of 6 per cent. per annum, and it reached a total of 183,225 in 1890. Since then the increase has been only 15 per cent. in 8 years, so that whereas the conditions at the time of the scheme led the designer reasonably to expect a population of 311,000 for 1898, the actual figure reached in that year in the eighteen munici-

palities dealt with was about 211,000. It may be assumed that a steady and normal rate of increase has now been reached, but it is noticeable that the population is distributed unequally over a large area. In accordance with this tendency, the drainage-area has been increased to 12,929 acres, as against the 10,600 acres tentatively allowed in the scheme, and as the same density (33 persons per acre) has been allowed for from the outset, the system now nearly completed will provide for a maximum prospective population of 424,230, as against 351,545 originally proposed. Kutter's formula for velocity of flow is taken as the basis of calculations.

The system is a "partially combined" one, and the sewers provide for the following allowances:—

Sewage flow	75 gallons per head per day.
Rainfall to be removed	2 inches per day over a catchment of 200 square feet per head

The sewage, one-half of which is to flow off in 6 hours, was estimated as that which might reasonably be expected with the improved water-supply, and is the same as that assumed for the northern and southern systems. There are 24 miles of main sewers, mostly of oviform shape and constructed in brickwork and concrete. Reticulating pipe-sewers are being rapidly extended, while house-connections are made compulsory as the street-pipes become available. The main sewers have cost £749,463. A rate of 1s. in the pound is levied on the rateable value, to cover the charges of repayments, interest, and annual maintenance. Three main intercepting sewers—the eastern, northern, and western—serve the suburbs concerned, uniting at Marrickville, near Cook's River, in a large junction-chamber. From this point the whole discharge gravitates through a triplicate circular outfall-sewer, over 2 miles long, to the sewage-farm at Rockdale, where it is treated by intermittent downward filtration.

The junction-chamber at Marrickville, where the three intercepting sewers unite, is shown in Figs. 9, Plate 3. It measures 27 feet by 22 feet 6 inches, and is built of bluestone concrete in the solid rock, access being obtained through the shaft by iron ladders. The three 6-foot outfall sewers leaving the chamber are commanded by penstocks, so that the flow may be diverted from any of them when necessary for cleaning or inspection. Over the mouths of the three incoming sewers light gunmetal gas-checks are hung. As is usual throughout the system, these are divided into segments, each segment being independently hinged so as not to impede the flow, while serving their intended purpose. As the chamber is near Cook's River, storm overflow-weirs are placed on

either side at five-sixths of the height of the outfall-sewers, and an overflow-duct 3 feet 9 inches in diameter leads from the chamber to the river.

The junction of these sewers was a matter involving much care, as they bring to the chamber the drainage of nearly 13,000 acres, whereon a maximum population of 424,230 is anticipated, and in which varying conditions prevail.

The three 6-foot outfall-sewers will be called upon ultimately to discharge a maximum combined or wet-weather flow estimated at 16,890 cubic feet per minute. The three sewers together would discharge this amount running 4 feet 6 inches deep. The maximum dry-weather flow would be discharged by two of the sewers, each running rather more than half full. As it will be many years before these requirements arise, it has not been necessary to complete the outfall length in triplicate throughout, only two of the 6-foot sewers being in use at present.

The eastern intercepting-sewer, which starts in Annandale, drains 2,934 acres and runs south-west through the populous suburbs of Petersham and Marrickville to the junction-chamber, having a total length of about 2¾ miles. It is of oviform cross section in concrete and brickwork, laid in trench and tunnel, and ranges in size between 3 feet 3 inches by 2 feet 2 inches and 6 feet 8 inches by 5 feet 8 inches. The gradients vary between 1 in 1,100 and 1 in 1,509. It receives branch sewers from Parramatta Road, Camperdown; West Kingston, Camden Street, Newtown, and Sydenham Road, Marrickville. A rising main from the pumping-station at Marrickville also conveys to this sewer the discharge from a large low-level system in that borough.

In the Illawarra Road there are two slight depressions which have to be crossed. The one, 968 feet in length, is negotiated by two lines of cast-iron pipes, 3 feet 6 inches in diameter, laid side by side on the same invert-line as the sewer; while on the other an inverted siphon has been used, 1,190 feet long, consisting of cast-iron pipes 3 feet 9 inches in diameter, with a sluice-valve and scour-channel at the lowest point, somewhat similar to the arrangement at the George Street siphon in the northern system. The sewage emptied from the siphon when it becomes necessary to scour flows to the Marrickville low-level pumping-station, and is lifted thence to the sewer below the siphon.

The northern intercepting-sewer drains an area of 2,340 acres. It starts in Leichhardt, and runs south through Petersham and Marrickville to the junction at Premier Street, the length being 3 miles 5·7 chains. It ranges in size between 3 feet 3 inches by

2 feet 2 inches and 5 feet 6 inches by 4 feet 6 inches, and the gradients vary between 1 in 520 and 1 in 1,509. A branch sewer from Dobroyd is carried over the valley of Long Cove Creek by an aqueduct 280 feet long, consisting of an oval tube, 4 feet 6 inches by 3 feet 6 inches, formed of riveted wrought-steel plates, and supported on masonry piers 50 feet apart.

The western intercepting-sewer starts in Strathfield and passes south-east through Burwood, Ashfield, and Marrickville to the Premier Street junction-chamber, having a total length of over 5 miles, and draining an area of 7,655 acres. The cross section ranges between 3 feet 3 inches by 2 feet 2 inches, and 7 feet 8 inches by 6 feet 8 inches, and the gradients vary between 1 in 520 and 1 in 1,509. This sewer receives branches from Elsie Street Burwood, from Five Dock, and from Carshalton, Webb, and Frederick Streets in Ashfield. Another branch sewer draining Canterbury, north of Cook's River, will ultimately be added. Practically the whole of these intercepting sewers with their branches were built in tunnel with bluestone concrete inverts and radiated brick arches, and were rendered up to springing-levels with 1 to 2 cement mortar. A list of the western system of main sewers is given in the Appendix, Table VIII.

The triplicate 6-foot outfall-sewer, from its junction with the intercepting-sewers to its outlet at the sewage-farm, is 2 miles 17 chains in length. As already mentioned, for present requirements two of the three sewers have been completed throughout, the third having been built where its construction was advisable for structural reasons, as in the tunnels. The sewers, laid side by side on the same gradient and level, pass south across Cook's River, and then south-east to the farm, across low-lying marshy ground broken by short sandstone ridges, which were pierced by tunnels. In crossing the flat valleys, several long aqueducts were necessary, and these added greatly to the cost of the work. Altogether an expenditure of £232,000 was involved by this outfall sewer.

The total length of the aqueducts is about 1½ mile, and of the tunnels, 47 chains. The sewers are carried over Cook's River and Wolli Creek in the form of two 6-foot tubes of wrought iron, supported by lattice-girder bridges, each bridge having two spans of 80 feet. The main girders are 162 feet long and 9 feet deep, and are placed 23 feet 6 inches apart. Space is left for the addition of a third 6-foot tubular sewer when necessary. The abutments are of concrete, and the centre pier, in mid-stream, consists of two 8-foot cylinders sunk through the silt of the river-bed to the rock and filled with concrete.

In the first and second aqueducts over the valleys of Cook's River and Wolli Creek, covering a distance of 1,088 feet, the sewers, still consisting of two 6-foot circular wrought-iron tubes, are carried on arches of 27 feet 6 inches span, and 3 feet 1 inch rise (Figs. 10, Plate 3). The arches are of brickwork 27½ inches thick, concrete being used for the spandrels and piers. The concrete superstructure is filled with sand, the top surface under the tubes being covered with tarred metal. Ornamental panels and string-courses of red and white moulded bricks relieve the general elevation, and dressed sandstone ashlar is introduced for the plinths of piers, keystones, and parapet-copings. The sewer-tubes are secured to cast-iron bed-chairs, which are fastened on the bridges to the cross girders, and on the aqueducts to cast-iron bed-plates held by anchor-bolts in the concrete. Expansion-joints, formed of short connecting lengths of double-socketed cast-iron pipe, are provided at intervals.

On the third aqueduct, 504 feet in length, nearer to the sewage-farm, the thickness of the brickwork in the arches is 18½ inches, each arch having a span of 28 feet and a rise of 4 feet. They carry a superstructure of concrete of square cross-section, in the body of which the 6-foot sewers, here three in number, are formed. The total top width is 25 feet, and the general elevation above ground is 18 feet.

On the fourth aqueduct, 1,900 feet long, entering the farm, the brickwork of the arches is 18½ inches thick and the span is 24 feet. The square concrete superstructure, 23 feet 6 inches wide, encloses three 6-foot sewers. Throughout these aqueducts the piers are of concrete, 4 feet thick longitudinally, with substantial footings. In places the ground is very soft to a great depth, and the piers in such cases rest upon hardwood timber platforms supported by numerous piles, driven, in some instances, 60 feet.

The outfall sewer has a gradient throughout of 1 in 1,700, and ends at the Rockdale sewage-farm in a straining-chamber. From this point the main carrier runs as a continuation of the sewer through the centre of the farm. This carrier, 2,500 feet long, is an open trough, with a waterway 8 feet 8 inches wide by 5 feet 3 inches deep, built on arches of 50 feet span, the whole structure being of concrete rendered with 1 to 2 cement mortar. Expansion is provided for by the insertion of ⅝-inch mastic joints vertically and transversely at the crowns of the arches. Wrought-iron rods, suitably disposed in the concrete at the sides and invert of the trough, were used to add strength and to economise space. The carrier ends in a second straining-chamber, from which the sewage is distributed to the filtration-areas.

Low-Level Areas on the Northern, Western, and Southern Systems.—One of the objects which it was from the first essential to achieve was the complete exclusion of the sewage from the harbour on the northern system and from Cook's River on the southern system. The gravitation sewers intercept the major portion, carrying the sewage to the ocean at Bondi or to the Botany and Rockdale sewage-farms; but certain areas being below the 40-feet contour-level, which is the limit of direct interception, more particularly on the harbour-frontages, it has been necessary to resort to mechanical means for raising the sewage therefrom to the main systems. The chief particulars of these low-level systems are given in the Appendix, Table IX.

The Pyrmont Area.—The harbour foreshores from Woolloomooloo to Balmain (Fig. 1, Plate 2), including densely populated portions of the city, form an extended low-level zone with an area of 1,666 acres. Where the ground slopes steeply to the waterside this zone is narrow, but it widens with the valleys at the heads of various bays, and is divided into sub-areas by spurs from the higher ground. A maximum prospective population of 68,500 is estimated for this zone, and the Pyrmont system provides for raising the sewage into the various branches of the main northern sewer. There are seventeen sub-areas, each having a distinct pumping-plant in duplicate. The sewage is collected by cast-iron pipes where internal pressure is possible, but otherwise ordinary vitrified stoneware pipes are used.

The selection of a method for raising the sewage, which would be most suitable and economical under the conditions, involved much careful consideration. Although a scheme combining electricity for one set of stations with hydraulic power for the remainder seemed to be the cheapest, the disadvantages in practice of a dual system decided the Author to recommend, in preference, a plan in which electricity would be used throughout. Obviously this course depended upon a cheap supply of electrical energy. It so happened that at the time a large generating-plant was being erected at Ultimo by the Railway Commissioners for driving the trams, and they agreed to supply the power necessary for the sewerage-works at 1*d.* per Board-of-Trade unit. This comparatively low rate, by reducing the probable annual cost, gave electricity the advantage over all other methods.

The energy is taken from the generating-station on three 37/13 cables to the central pumping-station, which is also a controlling centre, whence the power is distributed to the remaining pumping-stations.

The electro-motors and pumps are in duplicate for each sub-area, and are in concrete chambers below the surface where the ground would admit of their construction (Fig. 11, Plate 4).

Where the soil is soft and water-charged, cast-iron cylinders 27 feet by 20 feet have been used. These were cast in segments and were bolted up on the site through horizontal and vertical flanges. Each cylinder is divided into three compartments, the central one containing the pumps and electromotors, and those at the sides forming the pump-wells. The machinery is secured to the bottom of the pump-chamber, which is formed of concrete, and to steel girders extending across the cylinder.

The motors are compound-wound machines, ranging between 8 HP. and 58 HP. according to the duty required at each station. Armatures are of the iron-clad tooth-cored type, the field-magnets being so wound that the necessary load for starting does not exceed 40 per cent. of the normal working-load, which ranges, for the several stations, between 16·3 amperes and 84 amperes.

Pumps of the vertical duplex and triple plunger type are used, the suction varying between 6 inches and 18 inches.

In the pump-well at each station a vertical pipe is placed, in which an earthenware float actuates a recording-apparatus as the sewage reaches its highest or lowest normal level. By the movement of the float a circuit is made with the controlling-station, and this indicates upon the switch-board there the state of the flow. The attendant at the central station is in this way made aware of the level of the sewage in each pumping-well of the whole system, and, by switching the currents on or off, he can start or stop the motors and pumps at any station, as required.

A tell-tale circuit is made automatically when the outside attendant descends the ladder at each pumping-station on his rounds, and his arrival there is thus indicated to the central-station attendant, who is able to check his movements and communicate if necessary. The whole system is interconnected by telephone.

Some of the old stone or brick sewers discharging into the harbour carry a considerable dry-weather flow which it is necessary to intercept. For this purpose a tidal flap is placed in the sewer, the latter being, in most cases, tide-locked for part of the day. This flap, while keeping back the tide, stops the passage of the sewage, diverting it into the intercepting-pipe. It was imperative that the flap should remain closed against the egress of the sewage with the ebb-tide, and at the same time it should open to let any storm-flow escape, as otherwise damage would certainly result to

property on the low levels during heavy rains. The flap is therefore weighted at the top, thus tending to open, but is kept closed, against the escape of sewage only, by the tension of a chain affixed to a hydraulic cylinder. Floats are suspended on the upstream side of the flap, and these are balanced by wire ropes and pulleys with weights, the latter being connected with controlling valves on offlet-pipes from the hydraulic cylinder. When a heavy storm-flow occurs the floats rise and allow the weights to drop, opening the controlling valves, which are in duplicate. The pressure in the cylinder is then reduced and the plunger falls, relaxing the tension of the chain and allowing the flap to open. A third float and weight arrangement is provided as an extra precaution, and this opens an automatic relief-valve. The failure of these precautions would be indicated, in any case, by the flow at the nearest pumping-station, and a man could be sent to open the relief-valve by the hand-lever provided for use in such a contingency.

The Rushcutter's Bay Area.—The Darling Point and the Elizabeth Bay branch sewers of the northern system run along the spurs on each side of the Rushcutter's Bay low-level area, but in order to raise the discharge from this valley to the sewers mentioned a pumping-scheme was necessary. The area concerned is 106 acres, but as much of the ground is occupied by open reserves and market-gardens, the prospective population provided for is only 2,650.

The low-level sewers, consisting of ordinary 6-inch and 9-inch stoneware pipes, discharge at three pumping-stations, the first being at Ithaca Road, Elizabeth Bay, the second at Rushcutter's Bay, and the third at Yarranabbee Road, Darling Point. The Rushcutter's Bay controlling-station contains the necessary voltmeters, power-supply switch-boards, positive main switch-boards, and other electrical arrangements as in the Pyrmont system. The electric energy is taken from the adjacent tramway power-house at Rushcutter's Bay to the controlling-station and is thence distributed to the motors in the chamber beneath, and to those at the two remaining pumping-stations by 1·28 mile of 19/17 cable. The normal working-load for each station is 16·3 amperes. The pumping-plant, as in the Pyrmont system, consists at each station of compound-wound electromotors driving vertical duplex plunger-pumps, the motors and pumps being in duplicate, and one set in each case being capable of meeting ordinary requirements, leaving the other set available for use in case of emergency.

Particulars of the work to be done ultimately at each station,

as well as the capacity of the pumps, are given in the Appendix, Table IX. For the present population the daily discharge to be raised is about 50,000 gallons, and the length of sewers is 4,160 feet.

The Double Bay Area.—The Double Bay low-level zone, comprising 77·4 acres, is in the drainage-area of the northern system. This was the first low-level system undertaken in Sydney, and as the area was sufficiently large to justify the erection of a separate air-compressing plant, the Shone system was adopted. The general level is 6 feet or 7 feet above mean high-water level, and the subsoil is peat and sand, highly water-charged, so that the work generally was attended with some difficulty, although this would have been greater had a pumping-scheme been adopted. In that case, owing to the flat surface, good self-cleansing gradients in the sewers could have been secured only at the cost of a deep pump-well and a correspondingly high lift to the gravitation sewers, involving undue expense. The Shone system, by collecting the sewage at different points and delivering it more directly to the main sewers, admitted of smaller and shorter sewers laid at less depths and on better gradients, and, under the circumstances, was the cheapest method. Besides the daily dry-weather flow, calculated at 50 gallons per head of population, a portion of the rainfall equal to 2 inches per day on the catchment-area of back-yards and roofs is removed by the sewers. This area is drained by 6-inch cast-iron and stoneware pipes, which have an aggregate length of 8,117 feet. Automatic flushing-chambers are provided at dead ends where required, increasing the velocities to 5 feet per second.

There are four ejector-stations, each serving a sub-area and containing Shone ejectors in duplicate. The work done by each station, and the leading particulars of the system generally, are given in the Appendix, Table X.

To raise the maximum prospective combined sewage- and rainfall-flow, viz., 577·8 gallons per minute, 8·83 HP. will be required; and assuming the efficiency of the system to be 35 per cent., 25½ I.HP. will be required at the generating-station (Appendix, Table XI.).

The chambers containing the ejectors are cast-iron cylinders sunk at convenient sites. They were cast in segments and bolted up on the sites before sinking; the bottom sections are strengthened by cross girders of H section bolted to an inner flange of the cylinder. After sinking, each cylinder was floored with 12 inches of concrete to the top of the cross-girders, to which the ejectors were

then secured. Near each ejector-chamber a smaller cast-iron cylinder was sunk to form a collecting-chamber into which the sewers discharge, the sewage being thence admitted through a connecting pipe into the ejectors in the larger cylinder. From the collecting-chamber ventilating-pipes lead to high galvanized-iron up-cast shafts. Into these also the spent compressed air from the ejectors is expelled through a pipe with a nozzle attachment, and this materially assists the ventilating draught. The air- and delivery-mains are cast-iron pipes. All mains are in sections, allowing any branch to be cut out in case of accident; while to facilitate repairs when required, the delivery-mains can be emptied back into the sewers.

The air-compressing station is a plain single-storied brick structure, containing engine-room, accumulator-room, and office. The plant consists of two Parker shunt-wound motors, each actuating an air-compressor, space being left for duplicating this installation when the need arises. Each motor is capable of developing 25 HP. at a speed of 470 to 500 revolutions per minute when supplied at 500 volts, and the whole of the work can, if necessary, be performed by one motor at full speed. The electrical energy is taken over a 19/16 cable from the tramway power-house at Rushcutter's Bay, the cost being $1\frac{1}{3}d.$ per Board-of-Trade unit. By means of a claw coupling on the crank-shaft, from which both compressors are worked, the motors can be used separately or together, as required. The air-compressors are double-acting horizontal engines, the compressing-cylinders being 11 inches in diameter with 18 inches stroke, provided with water-jackets and all necessary fittings. The compressed air is delivered to mild-steel cylindrical receivers, 4 feet 6 inches by 9 feet, from which the air-mains are supplied. The air-pressure necessary for the ejectors varies with the sewage-flow between a minimum of 20 lbs. and a maximum of 28 lbs. per square inch. It was desirable to start and stop the machinery as these limits of pressure respectively were reached in the air-mains, and means were accordingly devised for governing automatically the series-parallel controller through which the current is supplied to the motors. Compressed air is admitted to either end of a small cylinder (A, Fig. 12, Plate 4). A bar prolongation of the piston-rod of this cylinder has attached to it a toothed rack (B) which gears with a pinion on the head of the controller-spindle (C). Along the bar, and immediately above the rack, stops are cut which correspond exactly with the positions at which the series-controller shaft will stop as it cuts out each successive resistance. The bar with these stops

passes through a die-plate (D), which is vertical to it and is so arranged that only one stop on the bar can pass through the plate at one movement, the next stop passing when the die-plate has moved a degree farther up or down. To obtain this intermittent action the die-plate is slowly moved by two hydraulic cylinders (E, E) at its top and bottom ends. The whole mechanism is controlled by a weighted valve (F) adjusted to rise with the minimum and to fall with the maximum pressure, admitting compressed air to either end of the air-cylinder and simultaneously supplying water-pressure to one of the hydraulic cylinders, and exhausting it from the other, according to the direction in which the rack turns the controller-shaft, starting or stopping the motors as the case requires. A storage-battery of 230 Epstein cells has been provided to supply power to run the plant at night when the tramway power-house is not available, and to reduce the drop in the line. The charging of this battery commences whenever the motors are stopped, energy being accumulated against their re-starting.

Efficiency-tests of the plant (Appendix, Table XI.) were made in the following manner:—Each day before starting, a man was placed at each ejector-station to count the number of times the ejector discharged during the time of trial, and thus the number of gallons of sewage delivered by each station was readily computed. The total lifts being known, the work done in each case was obtained. The compressor was kept going at a uniform speed of 50 revolutions per minute, which maintained an average air-pressure of 20 lbs. per square inch in the receivers. Indicator-diagrams were taken from the compressor at intervals, to obtain the average indicated horse-power. On starting each day, a reading of the watt-meter at the compressing-station was taken when an air-pressure of 15 lbs. per square inch was reached, and simultaneously a reading was taken from the watt-meter at the tramway power-house. At the end of the day similar readings were again made. By this means were recorded (*a*) the electrical energy leaving the generating-station, (*b*) the loss of energy on the line, and (*c*) the energy used by the electromotor at the air-compressing station. The loss of efficiency due to drop in temperature was obtained under normal working-conditions by taking the temperature of the air leaving the compressor and that at each ejector.

The Marrickville Area.—Marrickville, one of the leading western suburbs, has a population of about 20,000. Although most of the suburb is at a sufficient elevation to be intercepted by the western gravitation system, a portion comprising about 1,400 acres along the

Illawarra railway-line is very low, forming a basin with an outlet to Cook's River: in fact part of this basin is barely above mean high-water level. In the design of the western system this area was accordingly provided for by a pumping-scheme, which included the raising of the sewage to the gravitation system at a point on the main eastern intercepting-sewer at Illawarra Road. The original proposals, modified by later surveys, have been adopted in the works now in operation.

Unlike the low lands on the harbour frontage, this area has no ready run-off for surface-water, the fall to Cook's River being so slight that flooding has frequently occurred. A system of large open concrete drains has therefore been found necessary, in conjunction with the low-level sewers. Even with this adjunct, however, admission of a portion of the rainfall to the sewers is unavoidable. The allowances made were the following:—

Sewage	75 gallons per head per day.
Rainfall	2 inches per day on a catchment-area of 200 square feet per head.

The maximum prospective dry-weather flow is estimated at 3,375,000 gallons per day, and the maximum combined or wet-weather flow at 12,750,000 gallons. Half the daily dry-weather flow is assumed to pass away in 6 hours. There are 2 miles 13 chains of main sewers, and these converge at the pumping-station in Meeks Road. A long concrete reservoir runs underground alongside this building (Fig. 13, Plate 4). Into this reservoir the main sewer, 4 feet 6 inches by 3 feet 6 inches, discharges, and the sewage is admitted through penstock-openings to one or more of the pump-wells as required. The wells are 27 feet 7 inches deep below the engine-room floor, or 21 feet below high-water level. At a suitable height in the reservoir an overflow-weir is provided, over which any excess of wet-weather flow passes into a storm-water well, to be raised by an auxiliary centrifugal pump into the storm-water channels already referred to.

For present requirements the plant consists of two horizontal, compound, surface-condensing pumping-engines, a centrifugal pump capable of lifting 10,000 gallons per minute, and three Cornish boilers, each 20 feet by 5 feet, for a working-pressure of 100 lbs. per square inch. Space is left for additional engines and boilers, as two of the former and two of the latter will be ultimately required. Each main engine actuates a vertical single-acting pump, and is capable of raising 30 gallons per second, or, in emergency, 55 gallons per second, through a lift, including friction, of 40 feet. The high- and low-pressure cylinders are

15 inches and 30 inches in diameter respectively, and the stroke is 3 feet. Each engine has a guaranteed duty of 60,000,000 foot-pounds per hundredweight of coal consumed. This plant was made and installed by Messrs. Hathorn, Davey & Co., of Leeds. The rising main to the gravitation sewer is 2,155 feet in length, and consists of riveted steel pipes $22\frac{1}{2}$ inches in diameter. The cost of this low-level system, exclusive of reticulation lines, was as follows:—

	£.	s.	d.
Main sewer, 2 miles 13 chains	41,633	15	7
Pumping-station	7,991	6	0
Machinery	6,210	0	0
Rising main	1,832	7	8
Supervision and contingencies	5,766	1	6
Total cost	£63,433	10	9

The leading particulars of the main sewers are given in the Appendix, Table XII.

The Randwick System.—Randwick, a fine residential suburb to the south-east of the city, is built upon the high ground overlooking the ocean at Coogee Bay. Inland the hill slopes to a sandy level tract surrounding the Randwick racecourse, near to which is situated the model suburb of Kensington. With a portion of Waverley the whole forms a drainage-area of about 2,300 acres, carrying a population of 6,300; while a prospective maximum of 69,000 persons is allowed for.

The main sewer discharges into the ocean at the base of the high cliffs north of Coogee Bay. As usual, the partially combined system has been adopted, the flow allowed for being:—

Sewage	75 gallons per head per day.
Rainfall	2 inches per day on a catchment-area of 200 square feet per head.

The main sewer starts on the level tract near Kensington, and reaches the ocean after piercing the high coastal ridge in tunnel at a depth in places of 220 feet. Its total length is $3\frac{1}{4}$ miles. The uppermost portion, about 30 chains in length, consists of 18-inch and 21-inch stoneware pipes laid in trench on the lower ground, while the greater length is formed to an oviform section with concrete and brickwork in tunnel through hard rock. The sizes at this section range between 3 feet 3 inches by 2 feet 2 inches, and 4 feet 3 inches by 3 feet 3 inches, the gradients ranging between 1 in 580 and 1 in 1,600.

Subsidiary branches on the elevated ground discharge into catch-basins in the high shafts of the main sewer, and their

discharge reaches the latter through cast-iron and stoneware drop-pipes built in the shaft-walls (Figs. 14, Plate 4), tumbling-bays being placed at intermediate heights to break the fall.

North Sydney System.—In the year 1882 the sanitary condition of the locality comprised in this system became so bad that a sewerage scheme had to be prepared. The area is hilly and slopes to the shores of Middle Harbour on the north and Sydney Harbour on the south (Fig. 1, Plate 2); and as the slopes are steep no difficulty was experienced in devising a gravitation scheme.

The area it was first proposed to serve was 350 acres; 9½ miles of sewers were contemplated, and the cost, it was estimated, would be about £60,000. The environs of North Sydney are such that a sufficient area of suitable land could not be obtained for treating the sewage by broad irrigation, and as a good site was available at the head of Willoughby Bay in Middle Harbour, it was recommended that the sewage should be collected by means of intercepting-sewers from the southern and northern slopes, and be treated by precipitation and filtration. The site was admirable, as it did not entail a long outfall-sewer; while the surroundings are so precipitous that the probability of building in the immediate vicinity of the disposal-works is remote. The necessity for these works was beyond question, as the natural watercourses had become so polluted with sewage that they were little better than foul open sewers which were extremely dangerous to the health of the people residing along their course. In spite of this fact, however, the question was allowed to remain in abeyance until 1886, the population doubling in the interval. The matter would not admit of further delay, and it became imperative that the area to be served should be increased to 886 acres, and that provision should be made for an existing population of 12,000, and an ultimate maximum of 30,000 persons.

The growth of the neighbourhood continued to be so rapid during the construction of the works that provision has been made for extending the scope of the system to the adjacent suburbs of South Willoughby and Mosman; and the outfall-works now in operation are designed to treat the sewage from an area of 2,905 acres divided in the following manner:—

	Acres.
North Sydney	608
Mosman (North)	1,196
Mosman (South)	727
South Willoughby	374
Total	2,905

A population of 35 persons per acre was taken as a basis, and a daily dry-weather flow of 50 gallons per head was assumed, half of which is to be removed in 6 hours. There is a good run-off for surface-water, so that the sewers were designed to remove not more than ½ inch of rainfall per day in North Sydney, ⅜ inch per day in South Mosman, and ¼ inch per day in North Mosman and Willoughby. The present flow treated at the outfall is about 750,000 gallons per day. The leading particulars of the several main sewers are given in the Appendix, Table XIII.

The principal artery of the system has a length of nearly 2 miles, its highest invert-level, at Milson's Point, being 41 feet, and its outlet 20 feet 6 inches above mean high-water level. The sewer is oviform, built in concrete with brick arching round the upper half, and ranges in cross-section between 4 feet 6 inches by 3 feet 6 inches, and 3 feet 3 inches by 2 feet 2 inches. The gradients vary between 1 in 540, and 1 in 750. The level at the outlet is kept high enough to allow of the sewage passing, by gravitation, through its various stages of treatment before being discharged into Middle Harbour. Passing under the high land along Alfred Street, the tunnel in places is 260 feet deep. The sub-mains, however, are at a less depth, their contents reaching the main sewer through drop-pipes built in the sides of segmental shafts (Figs. 14, Plate 4). On the main line there are twelve deep shafts built of brick and concrete, which are provided with wrought-iron ladders and all appliances for inspection, flushing, and ventilation. The sub-mains are either brick and concrete oviform sewers or stoneware pipes, varied according to the requirements of the area drained. The chief sub-mains in North Sydney are those to Blue's Point and Lavender Bay, and like the mains, these are oviform sewers in tunnel through rock. To intercept the drainage of the southern half of Mosman, a branch sewer, 2 miles 25½ chains long, is now in course of construction. It starts near Little Sirius Cove, and after traversing the harbour-slopes as an oviform sewer in tunnel, finally discharges into the main sewer in Alfred Street. On this sewer a length of 85 chains will be built of pipes constructed on the Monier system. Sections of these pipes, with the method of packing in the tunnels, are shown in Figs. 16. The joint is effected by cement grout in the grooves shown at the ends of each pipe, thus forming a dowel all round. Under some circumstances the cheapness and speed with which such work can be done renders possible a great saving of money and time, as compared with the ordinary brick and concrete sewer. In the South Mosman branch the sewer did

not require to be larger than 2 feet 5 inches by 1 foot 9 inches, and the Monier construction enabled it to be built of that size; whereas with the ordinary materials, concrete and brickwork, the smallest size which can be constructed with advantage is 3 feet 3 inches by 2 feet 2 inches. Another sewer, the South Willoughby branch, 70 chains in length, is now being constructed, and like the Mosman branch, is an oviform sewer in tunnel through rock. Here also a Monier pipe, 2 feet 5 inches by 1 foot 9 inches, is being used.

The original method and site of the sewage-disposal works have been practically adhered to. The general arrangement of the works is shown in Fig. 18. Briefly the process in operation is the following. When the sewage has passed through screens to remove the larger floating solids, which are afterwards burnt, it is treated with lime at the rate of 1 ton per million gallons. The solids are reduced to sludge-cake and burnt in destructors. Sufficient land was purchased to enable the tanks and other works to be erected. This, with the portion reclaimed for the filtration-area, amounts to about 13 acres. The reclaimed portion, about 8 acres, was filled in with sea-sand to an average depth of about 5 feet, and was formed into eight filter-beds. Adjoining the outlet of the sewer and the buildings are five large open settling-tanks, built of concrete with brick lining and of such an aggregate capacity that for many years to come four will cope with the average daily sewage-flow, leaving the fifth as a reserve. These tanks are detailed in Figs. 19. Abutting on the settling-tanks, and so placed as to receive the deposited solids from them when required, is the sludge-reservoir, which is a long covered concrete chamber having a capacity of about 8,100 cubic feet. An open conduit of concrete superposed on the sludge-reservoir conveys the sewage to the tanks from the straining-chamber in the building (Figs. 19). The open effluent-channel, also of concrete, conveying the effluent from the settling-tanks, runs round two sides of the latter and then passes along the sides of the filter-beds, distributing its effluent through offlet valves and troughing over each bed as required. Willoughby Falls Creek formerly discharged into the head of the bay, and when this was filled in for the filter-beds it was necessary to build a storm-water channel to conduct the stream through the reclamation to the tidal waters (Fig. 18). This channel is also available as an overflow for the main sewage-conduit near the tanks, and relieves the works of any exceptional flow of storm-water. The filter-beds are protected on the harbour frontage by a rubble dyke, where a jetty has been provided for the use of the works.

The air-compressing plant consists of a Tangye horizontal steam-engine, type "H," which drives a horizontal double-acting air-compressor. The compressing-cylinder is 11 inches in diameter and 18 inches stroke, with water-jacket and all necessary fittings. Each settling-tank has a capacity of 93,750 gallons. All of them are so arranged that one or more can be used continuously, or each may be allowed to rest full before being emptied (Figs. 19). The arrangement of the machinery, filter-presses, sludge- and air-receivers is shown in Figs. 17. When the sludge is required to be drawn off from the tanks the latter are emptied of their liquid contents by the usual floating offlet-arm shown in Figs. 19, and the sludge is allowed to fall into a reservoir. Thence, after a second settlement, it gravitates through a 12-inch pipe into two close riveted steel cylinders (Figs. 17). Near these two cylinders, and of similar construction and size, is a third for compressed air, which is used at an average pressure of 80 lbs. per square inch. Through dip-pipes the sludge is forced up into the filter-presses directly above. The presses were made by Messrs. Manlove, Alliott and Co. of Nottingham, and were specially designed for these works. The cake is removed in a light truck from the press, spread on the floor, and mixed with one-third of its bulk of coke-breeze dust; after which it is thrown down shoots into the destructor-furnaces and is thus disposed of.

There are two destructors, one built on each side of the boiler-furnace, so that the heat evolved in the burning of the sludge coke is utilized to economise fuel (Figs. 17). Some difficulty was at first experienced in pressing, on account of the greasy nature of the sludge, but this has since been overcome. Steam injectors are provided to increase the draught in the destructors. The fumes pass round the boiler and over the fire-grate before escaping through the stack, which is 80 feet in height. After the sewage has passed through the filter-beds it is collected by under-drains consisting of perforated stoneware pipes laid in coke-breeze. These converge into an outfall-pipe, 21 inches in diameter, which discharges into Willoughby Bay slightly above mean spring-tide level. When drain-pipes in sand-filters have been made sufficiently porous to admit of the effluent passing freely into them, difficulty has been experienced in keeping the sand out. As the success of the filter-beds depends both upon the effluent passing into the pipes and upon the sand being kept out, it was deemed advisable to carry out some experiments before finally deciding as to the mode to be adopted at Willoughby Bay. Three tanks were constructed, each 4 feet deep and having a combined area of 0·9 square

yard. At the bottom of each tank a glazed perforated pipe was placed, surrounded with 6 inches of fine coke-breeze, the perforations being $\frac{1}{8}$ inch, $\frac{3}{16}$ inch, and $\frac{1}{4}$ inch in diameter, respectively. The boxes were then filled with sand to within a few inches of the top. Each tank formed a miniature sand filter, and as no sewage was available the city water was laid on. In the experiments, quantities were applied at rates varying between 4,240,000 gallons and 14,907,200 gallons per acre per day, when practically no sand was carried into the pipes. As not more than one-tenth of the smaller quantity would ever be put into the filter beds at Willoughby, it was, the Author thinks, safely assumed (*a*) that the perforations and coke surrounding the pipes would permit of the effluent entering the pipes faster than was required; and that (*b*) with the maximum flow of sewage, at the rate of say 400,000 gallons per acre per day, no sand would be carried into the effluent-pipe. The Author finally decided to adopt the $\frac{3}{16}$-inch perforations, as no more sand passed through these than through the $\frac{1}{8}$-inch perforations. It is also thought that the coke round the pipes will have the effect of preventing the growth of fungus in the perforations.

Samples of the effluents have been submitted to the Government Analyst, Mr. W. M. Hamlet, for examination, and the results (given in the Appendix, Table XIV.) indicate a very high degree of purification. Mr. Hamlet concludes that the effluents "may be safely allowed to run into rivers and tidal waters." In connection with the high amounts of carbonic acid, it may be observed that the sea-sand used for the filter-beds contains a large proportion of carbonate of lime, due probably to the presence of shells.

Reticulation.—Upwards of 300 miles of pipe-sewers are in use, with which over 55,000 houses are connected in the northern, southern, western, and north shore systems. All house-connections are carried out, under the regulations of the Board of Water-Supply and Sewerage, by licensed artisans, certificates being issued by the Board to property-owners on the satisfactory completion of the work.

Generally the reticulation-sewers consist of glazed stoneware pipes 6 inches to 24 inches in diameter. They are laid to discharge their maximum flow when one-half to three-quarters full, and to have self-cleansing velocities with the dry-weather flow. Manholes built in concrete to a conical form are placed at all junctions, changes of direction or gradient, or elsewhere at about 3 chains to 4 chains apart, to provide for flushing, cleaning, and ventilation. The pipes are generally laid at a depth of 7 feet or

8 feet, seldom increasing to more than 15 feet; where the main sewer intercepts, and where the latter is at a lower level, the junction is effected by means of a drop-pipe in the shaft-wall, tumbling-bays being provided if necessary. Junction-pieces are left on the lines for house-connections. The pipes are jointed with tarred gasket and 1 to 1 cement mortar. Automatic flushing-chambers fed from the water-mains are provided.

Ventilation of Sewers.—Before the advent of the Board of Water-Supply and Sewerage, the sewers laid in the city by the municipality were generally unventilated, while those constructed by the Government were ventilated only through the perforated manhole-covers. It soon became evident that other means would be necessary. The nuisance arising from the escape of sewer-air through the manhole-covers necessitated the erection of several exhaust-shafts, but even then the idea was that the manhole-covers should continue to serve as air-inducts. They were, however, so often choked by street-refuse as to be almost useless for the purpose, and it was then decided to erect induct-shafts similar to those used for exhausts. This system was so successful that, with subsequent improvements, it has been generally utilized. The galvanised wrought-iron riveted tubes used for these shafts are mostly 6 inches in diameter. All are fitted with exhaust- or induct-cowls, as may be required, and on the reticulation sewer lengths these are spaced about 500 feet apart. The main and lateral sewers are provided with much larger shafts.

From June to October, when a comparatively low temperature prevails on the surface, that of the sewer-air is higher, sometimes by as much as 10° F., so that the internal air-currents travel up-stream. In the summer months the temperatures in the sewers and at the surface approximate more closely, the former being slightly lower, so that the sewer-air sets down-stream. Apart, however, from temperature and barometric pressure, which undoubtedly influence the movements of the sewer-air, the chief agent in inducing the required currents was found by experience to be wind-action. Cowls were accordingly designed of such shapes as to induce, with the ordinary wind-pressure, either downward or upward currents as required, thus ensuring a systematic circulation of fresh air. There are now more than 3,000 of these induct- and exhaust-shafts in use, ventilating over 300 miles of sewers. By these means the air in the sewers is renewed twice to four times an hour with a moderate wind-velocity.

Water-sprays have also been adopted with success for inducing ventilation. These are in some instances combined with an

automatic flushing-arrangement. A $\frac{3}{4}$-inch water-pipe, fitted with a suitable nozzle, is connected with the manhole of the sewer, which is provided with an air induct-shaft. The spray issues from the pipe in the form of a cone, and acts as an injector. The water is drained into a chamber in which the flushing-syphon is placed. Mr. J. M. Smail, M. Inst. C.E., Engineer to the Board, to whom the Author is indebted for the results of the investigations on this subject, states that 213 gallons of water are used per hour in the spray, and that that quantity of water causes 62,000 cubic feet of air to circulate through the sewers in the same period. The work of the ventilating system is indicated in the Appendix, Table XV.

Storm-water Channels.—To provide for the removal of surface-water generally, channels of brick or concrete, open or closed, have been constructed along the several natural water-ways and valley lines (Fig. 1, Plate 2). The natural creeks, though swollen in rainy weather, were in dry seasons almost without flow, except for the foul waste waters that sluggishly passed along them, or stagnated in their uneven and winding beds, causing dangerous nuisances. It was therefore imperative in some cases, apart from better disposal of the rainfall, to substitute for the ineffective creek-bed a properly aligned and sloped channel. As the sewers were completed the channels were in all cases limited strictly to their proper function—disposal of the surface-water.

Generally the channels are designed to discharge from their drainage-areas a rainfall of 2 inches per hour. As nearly as desirable the old creek courses are followed, and the channels are of all sizes and forms, though generally they are open or covered concrete ducts, circular, elliptical, or flat in cross section, and rendered inside with 1 to 2 cement mortar. The concrete sides and inverts are as a rule 9 inches to 12 inches in thickness. A channel of typical construction is shown in Fig. 15, Plate 4. The street gutters are intercepted by a catch-pit or gully, from which a trapped pipe leads to the storm-channel. Upwards of 22 miles of these channels are now in use, 4 miles being open and about 13 miles covered, the remainder being stoneware pipes. The channel draining the valley between the Glebe and Balmain has a length of 2 miles and follows the course of the Johnstone's Creek, which it has superseded. At its summit it is 2 feet 5 inches in diameter and of circular section, and at its outlet to Rozelle Bay is an open concrete channel, 51 feet by 5 feet 4 inches, laid at a gradient of 1 in 1,216 and discharging at 3 feet 4 inches below mean high-water level. From this example it will be seen that

storm-water disposal has involved a considerable outlay, though it forms an inevitable corollary of the main sewerage. Where the main sewers intersect the channels, the latter are in places used as storm overflows. The sewage, overflowing only in exceptionally heavy downpours, is at such times much diluted, and is so quickly swept away to deep water as to cause no nuisance.

Manly System.—Manly, the chief watering-place of the capital, is picturesquely situated on a narrow neck of land between the north arm of Port Jackson and the ocean. This neck joins the high promontory forming the north head of the harbour to the mainland, and is flat and sandy, having a general elevation of 15 feet or 20 feet above high-water level. The population, now slightly over 3,000, is spread over an area of about 500 acres, partly on the flat ground and partly on the slopes on either side. As in the case of many other towns, a crude system of stoneware pipe-sewers did duty originally. These were laid to irregular gradients with no satisfactory arrangement as to size, with absolutely no ventilation and with inadequate provision for flushing. There were three outfalls, one at the harbour and two at the ocean beach, the latter two consisting of 18-inch cast-iron pipes carried over the sand into the ocean.

The new system, carried out under the Author's supervision, has been lately completed, and is now vested in the Municipal Council. The sewers are designed to carry a dry-weather flow of 50 gallons per head per day, one-half of the daily discharge being assumed to pass off in 6 hours. In addition to this, it is intended to remove the flow due to a rainfall of 1¼ inch per day over a catchment of roofs and yards amounting to 200 square feet per head.

The outfall-sewer commences at the Steyne or ocean promenade with an oviform cross section, 3 feet 9 inches by 2 feet 6 inches, and, changing to 4 feet by 3 feet, follows the sea-frontage with a gradient of 1 in 800 round the base of the cliffs and across the beaches of Fairy Bower and Shell Cove. It is constructed of concrete and protected by an ashlar masonry sea-wall, behind which, and covering the sewer, a promenade has been formed. Passing Shell Cove the sewer pierces a bluff headland in tunnel discharging into the ocean beyond at the base of an abrupt cliff, 160 feet high. Throughout its length the sewer is in a public reserve, and the existence of residences in the neighbourhood of its point of discharge, about 1 mile from the town, is not even remotely probable. This spot was chosen as being also well protected from direct wave-action; and although the invert at the outlet is 3 feet below high-water level, as necessitated by the low elevation of the

town, free egress is at all times allowed to the ordinary sewage-flow by the provision of a drop in the invert at a shaft near the mouth of the sewer. An expanding chamber nearer the outlet, with an open funnel, minimises the effects of any inrush, while additional security is afforded by a tidal flap.

With the exception of this outfall length, the main sewers are all stoneware pipes, 16 inches to 18 inches in diameter, laid to ensure a self-cleansing velocity with the maximum sewage-flow. At their upper ends automatic flushing-chambers are placed, supplied from the water-mains. The usual induct and exhaust shafts are used for ventilating. There are 7¼ miles of sewers of all sizes, and the works have entailed a cost of £19,400.

Rookwood Asylum Drainage.—At Rookwood, an outlying suburb to the west of the city, about 1,000 destitute men are accommodated in a large Government asylum. Previously the liquid sewage was utilized on prepared beds where vegetables were grown, and the solids were buried in the grounds of the institution. A short time ago the sanitary condition of the establishment rendered necessary a better method of disposal. The Author was accordingly asked to advise, and he recommended that as the septic tank with biological filters appeared to be giving satisfaction in England, and as this method could in all probability be followed with advantage in several schemes which he had under consideration, it was advisable that a trial on a fair scale should be made. As the Rookwood Asylum presented a favourable opportunity, he recommended that the trial should be made there. The proposal having received the sanction of the Minister for Public Works, the works were carried out and they have given complete satisfaction.

The site of disposal is within the asylum grounds, and the filtrate passes away through a 12-inch pipe-drain to a storm-water channel discharging into the Parramatta River. The general arrangement of the works is shown in Figs. 20, Plate 4. There are two septic tanks which have a capacity for 24 hours' flow, the discharge from the asylum being calculated on the basis of a water-supply of 50 gallons per head per day. Each tank measures 37 feet by 22 feet, and is constructed of concrete and covered by a light cement arch built on the Monier principle. The sewage enters and leaves the tanks by sunken weirs. The filter-beds, three in number, are placed side by side, forming a square and adjoining the tanks. The outside walls are of concrete and the dividing walls are of brickwork. Each bed measures 38 feet 9 inches by 14 feet, and the medium used is fine coke-breeze 3 feet 3 inches deep, covered by 8 inches of pea gravel. The capacity

of each filter for sewage is about 4,500 gallons, and the maximum daily flow, being about 50,000 gallons, necessitates each filter being charged four times, as a maximum, during 24 hours.

From the septic tank the effluent flows over an aerating cascade of concrete steps into a collecting gutter. From this gutter it passes through iron troughs to the outlet end of the filters (Figs. 20, Plate 4). Here a 12-inch cast-iron pipe running along the end wall of the filters receives the stream, and from this pipe each filter is supplied in rotation through offlets controlled by disk-valves. The filtrate-outlet from the bottom of each tank is fitted with a similar valve. The three supply-valves are keyed to one 3-inch shaft, and the three outlet-valves to another, each supply-valve being made to revolve with the corresponding outlet-valve below it by means of a connecting rod and cranks on the two shafts. All the valves are thereby reciprocating. They are worked automatically by the effluent itself which, when it fills each filter, overflows into a bucket suspended from a quadrant arm keyed to the shaft of the supply-valves. This bucket falls on being filled, and turns the shaft, causing every valve to move through one-third of a revolution. The bucket on falling strikes against a pin in the bed-plate below, which raises a plug and allows the bucket to empty, so that it can rise again by the time the filter has rested and is again ready for filling. The same action occurs as each filter becomes charged. The septic tanks can, when necessary, be emptied directly on to the filters. The contract price for the works was £2,688.

Willoughby and Chatswood Sewerage.—North-west of the city, and on the north side of Port Jackson, the country is very elevated, rising in a succession of ridges to a height of 600 feet or 700 feet above sea-level. The completion of a railway from North Sydney in this direction has resulted in recent years in the growth of several fine residential suburbs. Chief among these are Chatswood and Willoughby. As usual in such cases, the drainage found its way into the creeks, causing so dangerous a nuisance that it became imperative to devise a proper sewerage system. In response to municipal representations, the Author was instructed by the Minister for Public Works in 1897 to prepare a scheme, and the works here outlined have been nearly completed, the cost being estimated at about £20,000.

The drainage-area concerned is 867 acres, and the present population in the two boroughs is about 4,000. There being a very good fall from all sides to the main creek, which discharges into Sugarloaf Bay, an arm of Middle Harbour (Fig. 1, Plate 2), it was decided to adopt the "separate" system, allowing all surface-

water to pass into the creek. The collecting-sewers, which have now been carried out, are mostly 6-inch stoneware pipes laid at an average depth of 5 feet or 6 feet, and have an aggregate length of 9¼ miles. They converge to an outfall-sewer consisting of stoneware pipes varying in diameter between 12 inches and 21 inches, which follows the direction of the main creek for 1¾ mile, discharging at disposal-works near the tidal waters at Sugarloaf Bay. The pipes are designed to discharge the maximum sewage-flow when running half full, the flow itself being calculated at 50 gallons per head per day, and one-half of the daily quantity being assumed to pass away in 6 hours. Manholes for inspection, flushing, and ventilation, are placed about 4 chains apart, while at the summits of the collecting-sewers are automatic flushing-chambers supplied from the water-mains.

A combination of septic tanks and bacterial filters is used for the treatment of the sewage. Provision has already been made for about 6,500 persons, but sufficient land was reserved to permit of extension of the works until a maximum anticipated population of about 27,000 is reached. There are two septic tanks, each 75 feet by 41 feet 9 inches, and having an effective capacity of about 107,000 gallons. The effluent therefrom is treated by four filter-beds, which are arranged together so as to form a square, adjoining the lower end of the tanks. Each filter is 64 feet by 39 feet, and the filtrant is fine coke-breeze 2 feet 10 inches deep, underlaid by 10 inches of broken stone, and covered by 6 inches of pea gravel. The under-drains collecting the filtrate are of brickwork, open-jointed. Tanks and filters are built of concrete. The combined capacity of the tanks, which are open, allows of each resting full while complete liquefaction of solids is effected. The sewage in the first place passes through a grit-chamber where mineral matter is deposited. It then overflows into a concrete distributing-channel along the inlet end of the tanks, into any of which it passes by means of submerged openings, leaving in the same manner, so that the tanks are thoroughly trapped. From this channel the effluent is taken off by iron troughing to a point centrally situated between the four filters. A concrete chamber 10 feet in length by 5 feet in width is here formed, containing the automatic alternating-gear. The effluent from the tanks discharges into a tipping-shoot pivoted centrally, and as this shoot is canted to one side or the other, the different filters are fed. In the chamber below, an outlet-valve well and a float-well are provided to each filter, and all these wells are connected by piping and valves. By an arrangement of stop-boards, and by adjusting the valves in the chamber below, the filters can be made to work indefinitely in

any series. The filtrate is conveyed from the central chamber through iron pipes under the concrete floor of the filters, and is discharged into tidal waters.

Parramatta Sewerage.—The town of Parramatta, which has a population of 12,000, is situated 14 miles west of Sydney, at the head of the tidal waters of Parramatta River, a long estuary or arm of Sydney Harbour. The river above the town is fresh, being impounded by several dams. From this source the water-supply was formerly derived, till its contamination rendered necessary the erection of an ashlar dam across Hunt's Creek, a tributary of Parramatta River. From this place the water is pumped to a storage-reservoir, and after filtration it gravitates to the town. There are several large institutions in the town, including a gaol, two asylums for the destitute, a girls' industrial school, and a lunatic-asylum. These contain a total of over 3,000 inmates, and the sewage therefrom, as well as from part of the town, was discharged in a very concentrated state into the salt water below the lowest dam, where the river-bed is bare at low tide, so that a great nuisance was caused in the centre of the town. The excavation of a narrow channel in the river-bed and the erection of flood-gates somewhat mitigated the evil; but the sole remedy, it was seen, was an effective sewerage system.

In 1892 the Public Works Department prepared a scheme by which a total area of 1,383 acres was to be intercepted, the sewage being taken to a pumping-station to the east of the town and raised to a sewage-farm on the banks of the river, 1¾ mile down stream. It was proposed to treat the sewage by intermittent downward filtration, for which purpose the site, being mostly covered at high tide, was to be filled to 5 feet above high-water level with sand taken by dredgers from the river-bed.

This scheme, estimated to cost £76,000, entailed an annual charge for repayment and maintenance of 11*d.* in the pound on the rateable value of the property served. Under the circumstances the local municipal council shrank from incurring this additional debt. After further consideration the Parliamentary Standing Committee on Public Works in 1894 concluded that it was not desirable that elaborate and expensive works should be undertaken at the public cost for a municipality unwilling to accept the responsibility of repayment.

In 1897, owing to the intensification of the trouble in the hot weather, the matter was re-opened. Four schemes were then prepared by the Author, two containing, as alternatives to the sewage-farm, a treatment by the "International" system at the pumping-station nearer the town. As, however, land had been purchased

for sewage-disposal, it was resolved, especially as the area had ample potentialities for the purpose, that it would be wisest to adopt a scheme utilizing this ground.

The cost of the scheme accepted was estimated at £60,000, and the annual charge at £3,603, a considerable saving upon the first proposal. In 1896 the local council accepted the responsibility on a vote of the ratepayers. About one-third of the work has been carried out, and it is hoped that the whole scheme, which is somewhat modified so as to bring the work into line with present practice, will be in operation by the beginning of 1902.

The prospective population within 25 years was estimated at 32,500, and the ultimate number to be served at 48,500, representing a density of 35 persons to the acre. The sewers are on the partially combined system, and the following allowances were made:—

Sewage	40 gallons per head per day.
Rainfall	1¼ inch per day over a catchment of 200 square feet per head.

The two main creeks, tributaries of Parramatta River, have been converted into open concrete storm-water channels at a cost of £16,000. These channels have served a large area as sewage-outlets for some time, and on the completion of the main system they will be used as storm-channels only.

At the pumping-station at Clay Cliff Creek the sewage will pass through screens, and the heavier solids arrested will be burnt in a destructor-furnace which will also consume the town garbage.

Two pairs of centrifugal pumps will lift the sewage to the treatment-works, the lift, including friction, being equal to 25 feet head. Each pair is capable of raising the maximum flow, 1,200 gallons per minute. The destructor will contain four cells, so arranged as to be a means of economising the ordinary fuel for the boilers. Steam injectors will be used to induce a forced draught in the destructors, air being drawn to the furnace for this purpose from the main sewer, inducing ventilation in the latter. A subsidiary furnace will be added to ensure the destruction of noxious fumes should the temperature in the destructors fall through the dampness of the refuse; but, as all the gases are made to pass through the highly-heated main boiler-flue into the stack, 100 feet high, this precaution will seldom be needed.

The Paper is accompanied by drawings from which Plates 2, 3 and 4 have been prepared, and by a portfolio of detail drawings.

[APPENDIX.

APPENDIX.

TABLE I.—COST OF SEWERAGE WORKS DESCRIBED UP TO 31ST DECEMBER, 1899.

Item.	Cost
	£
Northern System, main works only	954,921
Southern System " " "	359,554
Western System " " "	749,463
North Sydney " " "	142,436
Randwick " " "	7,685
Chatswood-Willoughby	3,491
Manly	16,757
Rookwood sewerage	5,491
Parramatta sewerage (storm-channels)	23,197
Works constructed by municipalities and taken over by the Government	304,875
Reticulation sewers, ventilation, etc., carried out by the Metropolitan Board of Water-Supply and Sewerage	639,037
Approximate expenditure since 1st July, 1899, the date of the cost given above, up to 31st December, 1899	150,000
Total expenditure to 31st December, 1899	£3,356,907
Estimated additional expenditure required	758,806
Estimated final cost of works	£4,115,713

TABLE II.—DECREASE IN MORTALITY RATES DURING THE EXTENSION OF THE NEW SEWERAGE SYSTEM.

Period.	Mortality Rates per 10,000 from Specific Causes. Average of City and Seven adjacent Suburbs.				General Mortality Rate for Metropolis per 10,000.
	Typhoid.	Diarrhœa.	Phthisis.	Diphtheria.	
Before laying of sewers (1889).	3·48	11·2	10·8	5·2	189·2
After completion of Northern and Southern Systems (1897)	1·5	7·1	5·6	1·3	130·0

TABLE IIA.—DECREASE OF MORTALITY FROM TYPHOID FEVER IN THE CITY ALONE, DURING THE EXTENSION OF THE NEW SEWERS.

Year.	Population.	Rate per 10,000.	Year.	Population.	Rate per 10,000.
1884	118,645	8·43	1893	106,380	1·41
1889	116,490	5·07	1894	104,880	4·06
1890	113,470	3·79	1895	103,870	1·02
1891	109,090	2·66	1896	100,000	4·2
1892	106,380	1·76	1897	95,850	1·6

TABLE IIB.—COMPARATIVE PREVALENCE OF TYPHOID IN SEWERED AND UNSEWERED LOCALITIES DURING 1897.

Locality.	Population.	Density of Population. No. of Persons per acre.			Cases of Typhoid per 10,000 of the Population.		
		Greatest in any Locality.	Least in any Locality	Average.	Greatest No. in any Locality.	Least No. in any Locality.	Average.
Eight sewered districts . .	206,590	89·47	5·49	42·8	17·6	2·8	9·8
Thirty-one unsewered districts . . .	203,410	48·67	0·39	7·3	80·0	..	17·1

TABLE III.—MAIN SEWERS: NORTHERN SYSTEM.

Sewer.	Length. Miles.	Length. Chains.	Size at Outlet End.	Gradient. 1 in	Material Used.
Balmain north-western slopes sewer	1	74·84	3 feet 3 inches × 2 feet 2 inches	600	Brick and concrete
Balmain south-eastern slopes sewer	2	83·81	3 feet 3 inches × 2 feet 2 inches	1,000	" "
North main sewer, 3rd division	0	66·50	4 feet 3 inches × 3 feet 3 inches	1,509	" "
North main sewer, 2nd division	0	71·75	4 feet 6 inches × 3 feet 6 inches	1,509	" "
Glebe sub-main sewers	0	88·30	3 feet 3 inches × 2 feet 2 inches	540	" "
North main sewer, Glebe section	1	9·38	5 feet × 4 feet	1,509	" "
Camperdown branch sewer	1	14·50	3 feet 3 inches × 2 feet 2 inches	1,150	" "
Prince Alfred Hospital branch	1	23·50	4 feet 6 inches × 3 feet	909	" "
Pyrmont branch sewer	0	45·32	18 inches	490	Stoneware pipes
Northern main sewer, 1st division	1	29·10	5 feet 10 inches × 4 feet 10 inches	1,509	Brick and concrete
City intercepting sewers—					
Kent Street branch sewer	1	51·50	4 feet 6 inches × 3 feet	1,000	" "
Hyde Park " "	1	70·50	4 feet 6 inches × 3 feet	1,509	" "
Bourke Street " "	0	68·55	4 feet 6 inches × 3 feet	700	" "
Riley Street " "	0	12·12	3 feet 3 inches × 2 feet 2 inches	700	" "
Elizabeth Bay " "	0	67·40	3 feet 3 inches × 2 feet 2 inches	622	" "
Darling Point branch sewers	0	22·00	3 feet 3 inches × 2 feet 2 inches	1,000	" "
Waverley west " "	0	73·84	3 feet 6 inches circular	437	Cast-iron pipe, brick and concrete
Waverley east " "	1	42·90	3 feet 6 inches × 2 feet 4 inches	450	Brick and concrete
Outfall sewer	4	14·20	8 feet 6 inches × 7 feet 6 inches	1,509	" "
Total Length	25	9·00	..	..	..

TABLE IV.—NORTHERN SYSTEM MAIN SEWER—SIZES, DISCHARGING CAPACITIES, AND MAXIMUM PROSPECTIVE FLOWS.

Districts in each Drainage Area. (Plate 1.)	Drainage Area in Acres.	Number of Persons per Acre Allowed for.	Maximum Prospective Flows allowed for— Sewage from each Area.	Rainfall from each Area.	Combined Flow from each Area.	Cumulative Combined Flow after intercepting each Area.	Size of Oviform Main Sewer after intercepting each Area.	Gradient of Sewer.	Discharging Capacity of Main Sewer running Three-quarter full.
			Cubic Feet per Minute.	Cubic Feet per Minute.	Cubic Feet per Minute.	Cubic Feet per Minute.			Cubic Feet per Minute.
Balmain	1,200	42	840	583	1,423	1,423	4 feet 6 inches × 3 feet 6 inches	1 in 1,509	1,881
Glebe	378	42	265	183	448	1,871	5 feet × 4 feet		2,585
Newtown, Camperdown, &c.	526	45	394	273	667	2,538	5 feet 10 inches × 4 feet 10 inches		4,143
The City	1,692	47	1,325	2,131	3,456	5,994	7 feet 4 inches × 6 feet 4 inches		8,196
Paddington	356	42·637	253	175	428	6,422	7 feet 8 inches × 6 feet 8 inches		9,294
Woollahra	544	42·637	386	269	655	7,077	7 feet 10 inches × 6 feet 10 inches		9,896
Waverley W.	324	42·637	230	160	390	7,467	8 feet 2 inches × 7 feet 2 inches		11,213
,, E.	775	42·637	550	382	932	8,399	8 feet 2 inches × 7 feet 2 inches		11,213
,, N.	1,974	30	987	686	1,673	10,072	8 feet 6 inches × 7 feet 6 inches		12,366
Totals	7,769	..	5,230	4,842	10,072	..	Maximum Prospective Population 286,000. Length of Main Sewer 9 miles approximately.		

TABLE V.—AVERAGE DAILY FLOW IN SOUTHERN SEWER WITH QUANTITY OF SLUDGE REMOVED.

Year.	Average Daily Flow in Gallons.	Volume of Sludge per Year in Cubic Yards.
1891	900,000	1,600
1892	1,838,000	1,690
1893	1,500,000	879
1894	2,000,000	1,695
1895 to June 1896	2,059,000	1,960
1896–7	2,361,000	1,975
1897–8	2,675,000	2,005

TABLE VI.—DISCHARGES, DEPTHS OF FLOW, AND VELOCITY OF THE SOUTHERN OUTFALL SEWER.

Size and Gradient of Sewer.	Drainage Area in Acres.	No. of Persons per Acre allowed for.	Discharge in Cubic Feet per Minute during 6 Hours of Greatest Sewage Flow.			Height of Flow.		Velocity with Sewage Flow only. Feet per Second.
			Sewage at 1 Cubic Foot per Head per Hour.	Rainfall at $\frac{1}{16}$ inch over Whole Area per Hour.	Combined Flow.	With Sewage only.	With Combined Flow.	
5 feet 6 inches, circular. Gradient 1 in 1,320	1,306	47	1,023	3,944	4,967	1·6	4·0	3·02

TABLE VII.—MAIN SEWERS: SOUTHERN SYSTEM.

Sewer.	Length.		Gradient.	Size at Outlet End.	Material Used.
	Miles.	Chains.	1 in		
Bourke Street sewer . . .	1	33·0	266	4 feet 6 inches × 3 feet 6 inches oviform . .	Concrete and brick.
Elizabeth Street branch sewer .	0	72·0	340	24 inches in diameter . . .	Stoneware pipe.
Botany Road branch sewer .	0	31·0	350	18 inches in diameter . . .	"
Macdonaldtown branch sewer .	0	53·50	1,400	2 feet 6 inches in diameter .	Wrought-iron tube; concrete and brick.
Main outfall-sewer . . .	2	40·0	1,320	5 feet 6 inches in diameter .	Concrete and brick.
Total length .	5	69·50	..	..	..

TABLE VIII.—MAIN SEWERS: WESTERN SYSTEM.

Sewer.	Length. Miles.	Length. Chains.	Size at Outlet End.	Gradient. 1 in	Material Used.
Eastern intercepting-sewer, 2nd division	1	15·43	4 feet 6 inches × 3 feet 6 inches	1,509	Brick and concrete
Parramatta Road branch sewer	1	33·0	3 feet 3 inches × 2 feet 2 inches	900	" "
West Kingston branch sewer	0	22·25	3 feet 3 inches × 2 feet 2 inches	200	" "
Camden Street branch sewer	1	2·90	3 feet 3 inches × 2 feet 2 inches	1,000	" "
Marrickville low-level sewers	2	13·10	4 feet 6 inches × 3 feet 6 inches	800	Brick and concrete and stoneware pipes
Eastern intercepting-sewer, 1st division	1	50·0	6 feet 10 inches × 5 feet 10 inches	1,509	Brick and concrete and cast-iron pipes
Northern intercepting-sewer, 3rd division	1	11·40	3 feet 3 inches × 2 feet 2 inches	520	Brick and concrete
Northern intercepting-sewer, 2nd division	1	5·0	5 feet 3 inches × 4 feet 3 inches	1,580	" "
Dobroyd Branch sewer	0	60·0	4 feet 6 inches × 3 feet 6 inches	750	Wrought steel pipes and concrete
Long Cove Creek sub-branch	0	56·0	3 feet 6 inches × 2 feet 4 inches	750	Concrete and pipes
Northern intercepting-sewer, 1st division	1	41·0	5 feet 6 inches × 4 feet 6 inches	1,509	Concrete and brick
Western intercepting-sewer, 4th division	1	70·50	4 feet 9 inches × 3 feet 9 inches	1,340	Brick and concrete
Elsie Street branch sewer	0	66·62	3 feet 3 inches × 2 feet 2 inches	800	Stoneware pipes, brick and concrete
Five Dock branch sewer	..	..	..	..	..
Western intercepting-sewer, 3rd division	1	92·13	6 feet 8 inches × 5 feet 8 inches	1,600	Concrete and brick
Carshalton and Webb Street branches	0	58·0	18 inches	1,509	Stoneware pipes
Frederick Street branch sewer	0	68·37	3 feet 3 inches × 2 feet 2 inches	1,509	Stoneware pipes, brick and concrete
Western intercepting-sewer, 2nd division	1	22·64	6 feet 10 inches × 5 feet 10 inches	1,509	Brick and concrete
Canterbury branch sewer	..	..	..	..	..
Western intercepting-sewer, 1st division	1	28·69	7 feet 8 inches × 6 feet 8 inches	1,509	Brick and concrete
Outfall-sewer	2	16·80	6 feet circular Triplicate	1,700	Brick and concrete, wrought-iron tubes
Total Length	24	13·83	..	..	..

TABLE IX.—PYRMONT AND RUSHCUTTER'S

Name of Low-Level System.	Method of raising Sewage into Gravitation System.	Sites of Pumping-Stations.	Sewage flowing into Collecting-Well during Time of greatest Discharge.	Direct Lift.		Lift, including Friction.	
				Maximum.	Minimum.	Maximum.	Minimum.
			Cubic Feet per Minute				
Pyrmont	Vertical duplex plunger pumps, except at first two stations where triple plunger pumps are used; pumps driven by electro-motors; plant in duplicate at each station.	Pyrmont and William-Henry Streets, Pyrmont	175	39·86	27·03	51·27	38·44
		Near Wentworth Park	221	51·07	38·24	59·87	47·04
		Johnstone's Creek, near Booth Street, Annandale . . .	63	56·86	38·86	65·00	47·00
		Johnstone's Creek, near Piper Street, Annandale . . .	40	48·84	36·00	78·55	65·71
		White's Creek, near Brennan Street, Annandale . . .	31	57·28	44·40	73·24	60·41
		Abattoir Road, Balmain	38	61·12	41·10	74·50	54·50
		Roberts Street, Balmain	40	61·61	48·78	71·40	58·60
		Reynolds Street, Balmain	23	62·00	49·17	72·00	59·20
		Stephens Street, Balmain	56	72·65	53·40	76·70	57·40
		Morts Bay, Balmain .	27	65·08	47·08	70·78	52·78
		Snails Bay, Balmain .	21	78·23	60·23	96·70	78·70
		Washington Street, Darling Harbour .	38	33·58	20·75	44·98	32·15
		Sewerage Reserve, Darling Harbour .	22	36·58	23·75	41·14	28·31
		Munn Street, Darling Harbour	21	40·13	27·30	49·25	36·42
		Pottinger Street, Dawes Point . .	10	40·13	27·30	51·53	38·70
		Circular Quay . .	116	44·83	32·00	48·94	36·11
		Nicholson Street, Woolloomooloo . .	96	50·16	37·33	60·57	47·74
Rushcutter's Bay.	Vertical duplex plunger pumps, electrically driven as at Pyrmont.	Near Power House, Rushcutter's Bay .	24	40·55	27·72	49·67	36·84
		Ithaca Road, Elizabeth Bay . . .	6	44·53	31·70	55·93	43·10
		Near Yarranabbee Road, Elizabeth Bay	..	..	..	..	..

BAY LOW-LEVEL SYSTEMS.

Rising Main.		Diameters and Strokes of Plungers.				Revolutions per Minute.		Capacity of Pumps (equal to producing 4 Feet per Second Velocity in rising Main).	Combined Efficiencies. Motors and Pumps.		
Diameter.	Length.					Pumps.	Motors.		With Collecting-Well nearly empty.	With Collecting-Well half full.	With Collecting-Well nearly full.
Ins.	Feet.	Inches.		Inches.	Inches Stroke.			Cubic Feet per Minute.	Per Cent.	Per Cent.	Per Cent.
14	2,330	19⅝	and	13⅞	× 15	48	576	256·50	56	54	52
14	1,800	19⅝	,,	13⅞	× 15	48	576	256·50	56	54	52
8	950	14⅝	,,	10½	× 15	48	576	83·80	53·5	50·5	47
6	2,650	10½	,,	7½	× 15	48	720	47·10	52·5	51	48
6	1,400	10½	,,	7½	× 15	48	720	47·10	51·5	49·5	47·5
6	1,075	10½	,,	7½	× 15	48	720	47·10	51·5	48·5	45·5
7	1,000	10½	,,	7½	× 15	61	576	64·10	52·5	51	49
6	880	10½	,,	7½	× 15	48	720	47·10	51	49	47
8	470	14⅝	,,	10½	× 15	48	576	83·80	55	53	50
6	500	10½	,,	7½	× 15	48	720	47·12	50	47	44
6	1,620	10½	,,	7½	× 15	48	576	47·12	55	53	57
6	1,000	10½	,,	7½	× 15	48	768	47·12	42	39	35
6	400	10½	,,	7½	× 15	48	768	47·12	41	38	34
6	750	10½	,,	7½	× 15	48	768	47·12	39	38	37
6	1,000	10½	,,	7½	× 15	48	768	47·12	40	37	33
10	600	19⅝	,,	13⅞	× 15	48	576	131·00	52	49	46
10	1,518	19⅝	,,	13⅞	× 15	48	576	131·00	55	53·5	51
6	800	10½	,,	7½	× 15	48	768	47·12	41	36·5	32
6	1,000	10½	,,	7½	× 15	48	720	47·12	44	41·5	38
6	..	10½	,,	7½	× 15	48	720	47·12	45	42·5	39·5

TABLE X.—DOUBLE BAY LOW-LEVEL.

Particulars of the System.

From Ejector-Station.	To Ejector-Station.	Number of Acres.	Estimated Prospective Population connected with each Ejector-Station.	Maximum Dry-Weather Flow.	Volume of Rainfall.	Combined Maximum Discharge.	Ejectors. Number.	Ejectors. Capacity of Each.	Size of Sewage Sub-Main to Delivery-Main, in Inches.	Size of Delivery-Main, in Inches.	Size of Air-Main, in Inches.	Length of Sewage-Main to Delivery-Main, in Yards.	Length of Delivery-Main, in Yards.	Length of Air-Main, in Yards.	Approximate Velocity in Sewage- and Delivery-Main (Feet per Second).	Dead Lift, in Feet.	Friction in Sewage-Main to Delivery-Main, in Feet.	Friction in Delivery-Main, in Feet.	Friction in Air-Main, in Feet.	Total Lift, including Friction in Air- and Sewage-Mains, in Feet.	Horse-power corresponding to Maximum Lift.
				Gallons per Min.	Gallons per Min.	Gallons per Min.		Gals.													
1	2	11·00	330	34·37	47·75	82·12	2	50	4	..	3	273	..	273	3	38·96	7·40	..	0·89	55·02	1·87
2	3	42·25	1,268	132·00	183·87	315·37	2	150	6	8	3	5	119	154	3	38·67	0·48	2·36	0·61	47·53	4·54
3	4	12·00	360	37·50	52·06	89·56	2	50	4	9	3	336	185	{119 336}	3	38·96	10·83	3·06	1·61	56·81	1·54
4	Outfall	12·15	365	38·00	52·75	90·75	2	50	4	9	3	220	101	405	3	38·96	7·28	2·36	1·72	50·31	1·38
Total	..	77·40	2,323	241·87	336	577·80	..	..	..	..	..	..	..	..	..	..	..	..	..	..	8·83

TABLE XI.—DOUBLE BAY LOW-LEVEL.

Results of Efficiency-Tests.

Ejectors.									Compressors.							Line.			Efficiencies.						
Station.	Capacity in Gallons.	No. of Times Discharged.	No. of Gallons each Station Discharged.	Dead Lift.	Work Done per Station.	Total No. of Gallons Lifted.	Total Work Done.	Total Horse-Power-Hours of Ejectors.	No. of Compressors.	Diameter of Piston in Inches.	Diameter of Piston-Rod in Inches.	Revolutions per Minute.	Pressure in Receiver.	Mean Total I.HP.	Total Horse-Power-Hours of Compressor.	Total Board-of-Trade Units Used.	Total Horse-Power-Hours.	Loss on Line.	Efficiency on Line.	Efficiency of Motors and Shafting.	Efficiency of Compressor.	Efficiency Loss Through Drop in Temperature.	Net Results: Efficiency of Motors and Compressor.	Loss of Efficiency in Ejectors and Through Friction in Air- and Delivery-Mains.	Resultant Efficiency.
No.				Feet.	Foot-lbs.		Foot-lbs.						Lbs. per Sq. Inch.					Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	50	127	6,350	38·96	2,845,054	26,050	11,734,423	5·85	1	11	1·5	50	20	5·65	13·18	12·6	16·8	4·6	95·4	87	90	0·96	79	54	34·8
2	150	74	11,100	38·67	4,936,225																				
3	50	98	4,900	38·96	2,195,396																				
4	50	74	3,700	38·96	1,657,748																				

TABLE XII.—MARRICKVILLE LOW-LEVEL SEWERS.

Sewer.	Length.		Gradient.	Size at Outlet End.	Material Used.
	Miles.	Chains.	1 in		
Main Sewer—					
1st division . .	1	72·5	800	4 feet × 3 feet	Brick and cement.
2nd division .	0	66·5	420	3 feet 3 inches × 2 feet 2 inches	"
Sydenham Road Branch . . .	0	15·3	230	16 inches	Stoneware pipe.
Marrickville Station Branch .	0	28·8	140	9 inches	"
Renwick Street Sub-branch . .	0	1·00	320	12 inches	"
Total Length .	2	33·1	..	..	..

TABLE XIII.—NORTH SYDNEY SYSTEM, MAIN SEWERS.

Sewer.	Length.		Gradient at outlet.	Size at Outlet.	Material Used.
	Miles.	Chains.	1 in		
Lavender Bay Branch . . .	0	45·76	450	3 feet 3 inches × 2 feet 2 inches	Concrete and brick.
Blues Point Branch	0	35·81	370	3 feet 3 inches × 2 feet 2 inches	"
Glen Street Branch	0	10·49	90	3 feet 3 inches × 2 feet 2 inches	"
McDougall Street Branch . . .	0	2·56	100	9 inches	Stoneware pipes.
Mosman Branch .	2	16·38	970	3 feet 3 inches × 2 feet 2 inches	Concrete and brick, also Monier system.
South Willoughby Branch . .	0	69·67	350	2 feet 5 inches × 1 foot 9 inches	Monier system.
Middle Harbour Slopes Branch Main Sewer .	2	5·23	540	4 feet 6 inches × 3 feet 6 inches	Concrete and brick.
Willoughby Street Branch . . .	0	3·77	250	9 inches	Stoneware pipes.

TABLE XIV.—ANALYSIS OF EFFLUENTS FROM NORTH SYDNEY OUTFALL WORKS.

—	Effluent from Main Underdrain. Samples collected 5 July, 1899, at 10.30 a.m.	Effluent from Branch Underdrain. Samples collected 5 July, 1899, at 11 a.m.
Physical characters—		
1. Colour in 2-foot tube	Slight yellow tint	Slight yellow tint.
2. Clearness	Clear	Clear.
3. Odour	Scarcely perceptible	Scarcely perceptible.
4. Aeration	Fair to good	Fair.
5. Sediment	Slight	Slight.
Chemical characters—	Parts per Million.	Parts per Million.
1. Total solid residue	525	453
2. Chlorine as chlorides	104·28	99·28
3. Phosphates	Traces	Traces.
4. Sulphates	32·0	29·0
5. Organic matter—		
(a) Nitrogen as Nitrates	None	None.
(a) Nitrogen as Nitrites	9·0	5·0
(b) Ammonia Free	8·09	8·0
(b) Ammonia Combined	0·52	0·48
(c) Oxygen absorbed In 15 minutes	0·84	0·8
(c) Oxygen absorbed " 4 hours	1·73	1·65
6. Poisonous metals	None	None.
7. Carbonic acid	128·9	128·9

TABLE XV.—SHOWING WORK OF VENTILATION-SHAFTS.

Year.	No. of Shafts Tested.	Average Time of Test. Minutes.	Cubic Feet of Air per Hour.	Miles of Sewer Ventilated per Hour.	Average Wind-Velocity. Miles per Hour.
Average of One Exhaust Shaft.					
1895–6	1,026	11	2,932	2·74	10·72
1896–7	1,225	25	3,173	2·96	11·19
1897–8	1,436	28	3,018	2·80	12·90
Average of One Induct Shaft.					
1895–6	520	13	3,917	3·74	10·72
1896–7	634	27	3,636	3·45	11·44
1897–8	724	25	3,523	3·36	13·20

Exhaust Work, 1897–8.—1,398 6-inch shafts, thirty-six 9-inch shafts, one 16-inch shaft, fifteen stacks steam-shafts and water-sprays. Total exhaust per hour, 5,637,930 cubic feet of air.

Induct Work, 1897–8.—716 6-inch shafts, eight 9-inch shafts, fourteen water-sprays. Total per hour, 3,800,372 cubic feet of air.

(*Paper No. 3267.*)

"The Bacterial Treatment of Trades Waste."

By William Naylor, Assoc. M. Inst. C.E.

Although much attention has been paid to the treatment of sewage on bacterial filters, little has been heard, up to the present time, concerning the treatment of trades waste in like manner.

The bare fact that in the majority of cases trades waste is likely to be strongly acid or strongly alkaline, or, worse still, charged with chemicals of an antiseptic character, has deterred many from even entertaining the idea of resort to bacterial methods of treatment in connection therewith. The Author was induced to pay special attention to the subject by two causes: first, the oft-recurring statement that the sewage of a particular place was difficult to treat because of the admission to the sewers of trades waste; and second, the unexpected behaviour of samples of trades waste left standing in unstoppered bottles.

With regard to the first of these considerations, while it must be admitted that in many cases the cost of sewage-treatment is increased by the influx of trades waste, it is only in rare instances that difficulty has occurred in the treatment at outfall-works, such as to call for radical modification of the methods of treatment commonly applied to domestic sewage. Cases within the Author's experience are:—Galvanizers' pickle at Wolverhampton, Tipton and Bilston; refuse from tanneries and glove-factories at Colne and Yeovil; alkali-waste at Burnley and St. Helens; brewery-waste at Shepton Mallet and Blackburn; woollen-mill and felt-factory waste at Bradford and Nuneaton; bleachworks-waste at Burnley and Horwich. In only two of these cases has any real difficulty arisen.

Examining these kinds of waste more closely, galvanizers' pickle is a common salt of iron, often used as a precipitant for ordinary sewage. It is true it is occasionally accompanied by some free acid, but this only calls for sufficient lime for neutrali-

zation in the precipitation-tanks, and the tank-effluent is then normal. At Wolverhampton, during two years' observation, the Author never discovered a tank-effluent which failed to putrefy on standing, in spite of the fact that the crude sewage contained, in addition, waste and wash-liquors from ammonia and tar-distillation shift-stop liquors, which are generally assumed to have, and probably will have, sterilizing effects in the absence of considerable dilution.

Alkali-waste may be placed in almost the same category as the Black Country waste, for when the sulphides are precipitated by ferric salts the tank-effluent is normal, and the sulphides in the sludge on exposure are almost immediately oxidized. The sewage of St. Helens has recently been treated successfully on bacterial filters. The waste from tanneries and glove-factories may be regarded simply as strong sewage, that from both Colne and Yeovil being quite amenable to bacterial treatment.

Wool-scouring liquors admitted to sewers cause difficulties of a mechanical rather than a bacterial character. Whether these are crude liquors, or the mother-liquors after recovery of grease, a certain amount of fat is included in their burden, and in the latter case some little free acid. If the acid be not neutralized by the soaps natural to the sewage, a little extra lime at the outfall soon settles this matter; but the greater objection is the fat. Quantity is here an important factor, for whereas at Nuneaton the discharges of a greasy nature from fellmongers, hat-works and wool-scourers, are borne by the sewage to the outfall without preventing the production of a satisfactory effluent by ordinary means, at Bradford the character of the sludge formed, which is more or less an emulsion, has hitherto almost defied pressing or handling in any form. At the same time, evidence that the tank-effluent can be treated satisfactorily on bacterial filters is fairly conclusive, and there are no scientific reasons to the contrary.

Bleach-waste and brewery-waste call for special consideration. At this point it will only be said that, whereas at Burnley and at Blackburn bleach-waste and brewery-waste, respectively, is received into the sewers without giving rise to abnormal developments, at Horwich and at Shepton Mallet bleach-waste and brewery-waste, respectively, is admitted to the sewers with disadvantageous consequences, although at the latter two places the ratio of waste to sewage is much greater.

The number of trades-waste samples drawn and examined by the inspecting staff of the Ribble Joint Committee averages fifty per month. After examination many are kept as exhibits. It

has been observed that the majority of these, so long as they are not acid, are subject to distinct changes on standing unstoppered. Slightly alkaline samples become neutral; then follows a deposition of colouring matter; and this is succeeded by the growth of either a mould or a green vegetation. The sample filtered from this is clear, sweet-smelling, and lightly charged with dissolved solids. Time and contact with the air being apparently the all-important elements, trials were made with the object of discovering whether these desirable changes could be hastened by artificial means.

A small bacterial filter was constructed, primarily brought into condition by sewage, and provided with a revolving feeding sprinkler; when it was found quite practicable to obtain satisfactory results, especially where the waste had been considerably diluted, that is, where the liquors treated consisted largely of wash-waters. Where much free chlorine was present this was not the case; and where, as in print-works waste, colour-shop waste, distillery-waste, or strong brewery-waste, starch-products were dealt with, a "souring" took place which very soon impaired the usefulness of the filter. In the last three waste liquors an acid fermentation is set up spontaneously (due largely to the lactic acid ferment) which actually continues during the sprinkling of the filter. It may of course be contended that this particular fermentation is just as much a purification as any other bacterial change, seeing that the result is the disintegration of certain objectionable constituents of the waste. But the time taken for satisfactory purification and clarification while acid fermentation is proceeding is considerable, some of the stronger liquors requiring eight, nine, and even fifteen successive filtrations.

The introduction of competitive and more active organisms—the anaerobic bacteria of putrid sewage—has the effect of preventing the souring almost completely in liquors containing starch or starch-products. A trial of this was first made with ordinary starch. About 20 lbs. of starch were mixed with 10 gallons of hot water forming a paste. One-half of this was mixed with 1 gallon of putrid sewage-sludge, and, after having been left standing for one day, was examined. After the expiration of five days a further sample was examined and then the mixture was passed through the filter. It may be desirable to mention here that, broadly speaking, the products of starch on inversion by acid are dextrose and dextrin; on conversion by diastase, as in brewing-operations, maltose and dextrin; and by spontaneous fermentation a mixture of these products and others, including acids more or less defined.

The dextrose or maltose produced may be measured by the

amount of copper oxide reduced, but the dextrin has no reducing-power. As, however, each of the products maltose, dextrose, and dextrin, has a certain optical activity, the amount of dextrin present with either of the other two products can be determined by subtracting the rotatory angle due to the quantity of maltose or dextrose present (as measured by means of copper oxide) from the total rotation due to the mixture of the two. From the results shown in Table I. (Appendix), it may be observed that the difference in the composition of the mixture after standing one day is little more than that due to the dilution or to experimental error. At the expiration of five days, however, there is a decided change. The copper oxide reduced amounts to less than one-half, as does also the rotatory angle. This indicates decomposition of the starch to the extent of one-half or more. The remaining portion of the paste, unmixed with sewage, was unchanged in appearance and gave practically the same figures on inversion as on the first day, but smelled offensively.

After passing the mixture, five days old, slowly through the filter once, the copper oxide reduced was diminished to less than one-tenth, and the rotatory angle to less than one-half. The albuminoid ammonia—due, of course, to the added sewage—was then estimated for the first time and found to be 0·16 part per 100,000. The liquid was filtered repeatedly up to five times, the operation extending over about two working-days, and Table I. shows the changes after the successive filtrations.

The other portion of the starch-paste had now become sour and stinking, though otherwise thick, slimy, and grey as at first, and was passed into the filter; but up to the twenty-first filtration a satisfactory effluent was not obtained, and the activity of the filter was impaired if not destroyed. The effluent was turbid, soured on standing, and gave a blue coloration with iodine, indicative of unchanged starch.

About this time, Mr. John Stanning being anxious to improve the condition of the effluent at the Leyland works of the Bleachers' Association (the purification-plant at which has been described by the Author in the Proceedings[1]), the Author, on the success of the experiment described above, suggested treating the worst liquors only, in the same manner, and an attempt was made with kier-liquors. These amount to only about 20,000 gallons daily, but as they are produced by boiling raw cloth, first with lime and afterwards with soda, they are very foul and concentrated, apart

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 390.

from the strong alkalinity (nearly one-tenth normal). The most objectionable feature of the waste was its extreme alkalinity. But in spite of the difficulty experienced in preserving the alkalinity of exposed liquors when desirable for processes inside factories, and knowing the derision with which practical manufacturers would receive a process of impounding, sprinkling, and filtering alkaline liquors for any purpose, and retaining the alkalinity, the trial was proceeded with.

Eight parts of kier-liquor were mixed with one part of wet sewage-sludge and were allowed to stand for 1 week. Table II. (Appendix) shows the reduction in alkalinity, the only noticeable change due to standing. But, after being sprinkled three times over a 3-foot filter of broken clinker, previously brought into condition by sewage, the change was remarkable, the albuminoid ammonia being reduced to nearly one-quarter and the effluent becoming clear and neutral in reaction. The nitrates present were, in the Author's experience, phenomenal; due, of course, to the added sewage. The Table shows also the effect of two weeks' standing, but the advantage is not so considerable as to justify the expenditure involved in the extra tank-accommodation. It is probable that better results would be obtained for less capital expenditure, if more of the outlay was applied to the provision of larger filtering-area.

In view of these results, it was decided to install filters and to modify the tank system for the treatment of the whole volume of liquors, amounting to 500,000 gallons daily; and although, as these are only now in course of construction, no results can be given, those from a similar but smaller installation at a bleach-works and calico-print works—probably the first installation of its kind—can be cited.

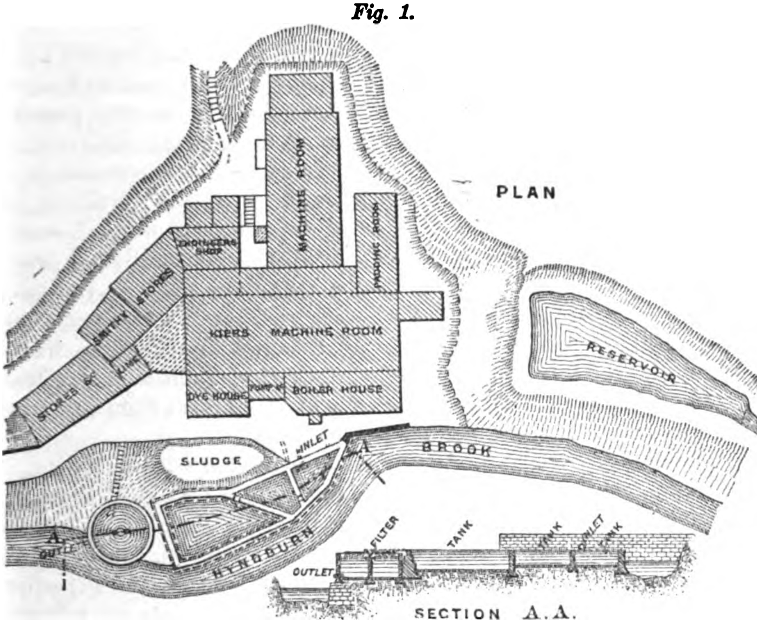
The works are those of Messrs. Peel, Tootal & Co., of Baxenden. In these works the processes are uniform from day to day, and consist of boiling grey cotton cloth, first with lime and afterwards with soda. These boilings are followed by an acid wash, and then a chlorine bath, apart from certain intermediate and final washings. The wash-liquor, therefore, contains lime, soda, chlorine, and the various substances removed from the crude cloth (starchy sizes, china-clay, etc.), as well as adventitious dirt from the floors and workshops. Some dyeing is also done, and the waste liquors from the dye-becks also find their way to the main outfall.

For some three or four years before July, 1900, the firm had struggled with precipitation-tanks and ordinary continuous-flow filters without success. At that time proceedings were instituted under the Rivers Pollution Prevention Act, and as a result it was

decided to try bacterial treatment. At the outset, the capacity of the tanks was increased so as to be equal to not less than three days' flow. The tanks are common impounding-tanks provided with floating arms, and are all connected and used as one large septic tank, *Fig. 1.*

The continuous overflow from the tank runs into a hopper over the revolving sprinkler, which delivers on to a filter of furnace-ashes of graduated size, the largest of which, forming the bottom layer, pass through a 2½-inch ring, and the smallest, forming the

Fig. 1.



Scale, 1 inch = 80 feet.

INSTALLATION AT THE WORKS OF MESSRS. PEEL, TOOTAL & CO.

top layer, are retained by a ¼-inch mesh. Each filter has an area of 60 square yards and a depth of 11 feet. When the plant was first put into operation, about 4 tons of old sewage-sludge was delivered into the tanks, and they were then filled with ordinary liquors. After standing until the mass became putrid (*i.e.*, for about four days), the ordinary liquors were introduced and the filter was fed. To maintain the putridity, all the works-closets were connected with the tanks, and in case of any falling off in that respect, sewage-sludge was added from time to time. This, however, was not found necessary to any considerable extent.

As is the case with all bacterial filters provided with sprinklers, a small amount of suspended matter is delivered with the final effluent, but in this case it is intercepted by a small sand filter.

The working of the plant has been very satisfactory. The effluent is clear and colourless, in spite of the raw liquors varying from a deep purple to a chrome yellow. It is sweet, neutral, contains nitrates and little albuminoid ammonia; and the effect of the antiseptic free chlorine is nowhere observed. The filter is quite active bacterially, and treats successfully 350 gallons per square yard. A further filter is being installed.

The results of working are shown in Table III. (Appendix), and were obtained with a depth of only 4 feet of filtering material.

The most noticeable feature in the working of the plant at Messrs. Peel, Tootal & Company's works, is that the free chlorine present in the crude waste does not, as might be anticipated, interfere in the least with the bacterial activity of the filter. Presumably it becomes combined in the septic tank with the products of decomposition set free in the putrid sewage. The bleach-waste discharged into the sewers at Horwich is evidently of such volume as to leave a surplus as the tanks are used at present; though it is possible that if they were used on the septic system the difficulty would disappear. At Burnley, bleach-works waste containing no inconsiderable amount of free chlorine is admitted to the sewers, and a satisfactory effluent is obtained from bacterial filters, but the tanks are of open septic type.

Brewery-waste and distillery-waste is treated with difficulty, if at all, on bacterial filters directly, owing to the formation of acids. A sample of crude beer was sprinkled twenty-three times over a bacterial filter 3 feet deep, the loss due to evaporation being continually made up with water; but on each successive filtration the filtrate was sour, and though a considerable change was effected in the liquor, at the conclusion it was of a dark brown colour, muddy in appearance, sour and offensive. Another sample was allowed to stand for five days in contact with one-fifth of its volume of wet putrid sewage-sludge from a septic tank, and was then sprinkled over and passed through a filter. Table IV. (Appendix) shows the result of this operation; and it may be seen that after the second filtration, both the optical activity and the reducing-power had disappeared, and that the fifth filtrate was an excellent effluent showing a diminution in total solids from 3,200 parts to 200 parts per 100,000. The effluent was clear, sweet, colourless and neutral, but contained a small amount of suspended matter. Five filtrations may appear to be an excessive

number, but it must be borne in mind that the strength of brewery-waste would be only about one-fifth, and that of distillery-waste about one-half to one-third of the strength of crude beer. The following Table gives the relative volumes of the liquors:—

Volume of the Liquors per 100 Gallons of Brew.

——	Brewery A.	Brewery B.	Brewery C.
	Barrels.	Barrels.	Barrels.
Washing of hot liquor backs	5	4	4
Washing of cold liquor backs	..	..	..
Cleaning out mash-tun	4	..	..
Copper wort-pipes	2	15	17
Two wort-backs	3	..	..
Copper including last runnings from mash-tun to save copper during raking of fires	25	20	20
Hop-back, pumping-back	8	15	18
Wort-pumps	..	..	..
Cooler and refrigerator	9	20	16
Fermenting-tuns, yeast	..	..	..
Back and yeast press	8	16	20
Settling-backs	2	4	4
Floors upstairs	4	10	10
Racking-room	3	5	5
Sundries	10	..	..
Casks, first washings	30	50	40
Casks, second washings	30	50	60
Casks, steaming and outside washings	100	20	80
Total in gallons	9,108	8,604	10,944

In distilleries by far the larger volume of the waste is the potale; although in cases where the grain is malted—and these are numerous—the "steep" water is considerable, as are also the "spent lees" and "lime washings" from the rectifiers and tun rooms.

The following are the volumes of waste of each kind at eleven representative distilleries on the River Spey, Scotland:—

Number.	Potale.	Steep Water.	Spent Lees.	Lime Wash.
	Gallons per Week.	Gallons per Week.	Gallons per Week.	Gallons per Week.
I	50,000	25,000	30,000	20,000
II	30,000	10,000	11,000	5,000
III	24,000	20,000	7,000	35,000
IV	58,000	36,000	21,300	40,000
V	29,000	18,000	10,650	15,000
VI	27,500	6,000	6,510	3,600
VII	27,500	6,000	6,510	3,600
VIII	30,000	40,000	15,000	15,000
IX	10,000	15,000	6,000	1,000
X	25,000	16,000	8,000	8,000
XI	31,000	18,000	4,000	18,000

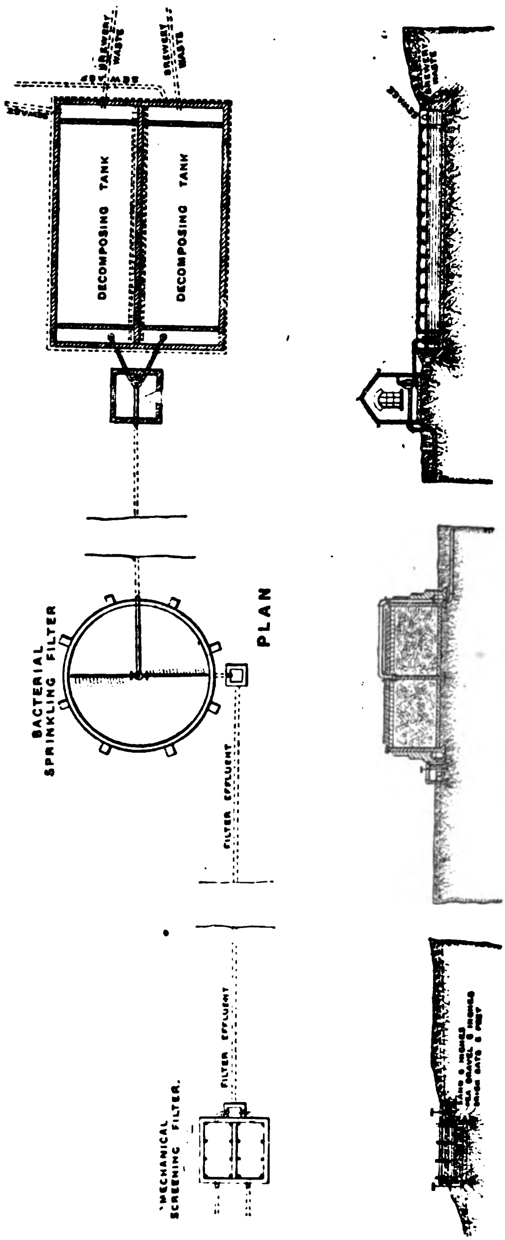
An average distillery may be considered to discharge about the same volume of waste liquors as an average brewery, namely 25,000 gallons to 35,000 gallons daily, and almost any method of treatment applicable to one is applicable to both.

At the Hook Norton Brewery Company's brewery, Hook Norton, Banbury, a settling-tank and continuous-flow sand-and-gravel filter was used, but with little success, during the six years ending 1898. It was then tried intermittently with no better result, and, on the suggestion of the Author, the plant was remodelled in 1900 in the manner shown in *Figs.* 2. The flow is reduced, by eliminating all clear water, to about 12,000 gallons of strong liquor per day. This is impounded in a settling-tank for not less than twenty-four hours in contact with putrid sludge from sewage, or 5 per cent. of domestic sewage is admitted to the tank, and when the putridity has once been established, sewage-sludge is no longer necessary. The contents of this tank, which may be termed an "anti-souring" rather than a septic tank, are pumped continually by a pulsometer delivering into the hopper of the sprinkler over the filter. After being first brought into condition by means of sewage only, the filter was started on the 7th June, 1900, and Table V. (Appendix) shows the results of the first four months' working. The filter is in better condition than when it was started.

The filtering-medium is coal, screened and graduated in size from about 1-inch cubes at the bottom to ¼-inch cubes at the top. The Company, being well provided with steam, were prepared (under threat of legal proceedings from two sources) to pump the first filtrate on to a second filter for further purification, but this was not found necessary. The little suspended matter present after the first filtration is intercepted by shallow sand filters, and the effluent is clear, neutral, colourless, sweet, contains nitrates, and liberates albuminoid ammonia to the extent of about 0·1 part per 100,000. The diminution of dissolved oxygen after saturation, is less than 30 per cent. Similar installations are being made at the Fountains Free Brewery, Blackburn, and, in a modified form, at Messrs. Sumner's Brewery, Haigh, Wigan.

The difficulty with regard to free chlorine having been overcome in the case of bleach dye-works, Messrs. Wiggins, Teape & Co., of Chorley, Lancashire, decided in August, 1900, to try the effect of bacterial treatment on the waste from their paper-mill. The effluent from the mill was fairly clear, having been settled and filtered through continuous filters of animal charcoal. Complaints, however, were made by riparian owners on the River Lostock, some distance below the works, as considerable decomposition took

Figs. 2.



SECTIONAL ELEVATION
Scale, 1 inch = 40 feet.

INSTALLATION AT THE HOOK NORTON BREWERY.

place, with the usual offensive emanations. By this time the sterilizing effects of the chlorine had evidently been annulled. The most objectionable constituent of the crude liquors is the organic matter from the old rags used, and the starchy and fatty sizes from the new unbleached cloth or "parings." It was decided first to try the bacterial filter with sprinklers on the ordinary tank-effluent. Fairly satisfactory results were obtained by this means, but as the effluent was turbid, probably owing to the presence of finely divided particles of china-clay, sewage was added, and Table VI. (Appendix) shows the results obtained for a period of about three months, including the time before and after the addition of sewage. The installation is practically identical with that at Messrs. Peel, Tootal & Co.'s works, and the Hook Norton brewery. The results are highly satisfactory—one of them, of no little importance, being the absence of the turbidity due to the coagulating effect of the sewage. In almost all mills where esparto grass is used, much difficulty is experienced in obtaining a clear effluent, even after filtration through very fine ashes. After admixture with sewage, however, and sprinkling, the final effluent contains much less suspended matter than that from brewery-waste.

The Paper is accompanied by two tracings, from which the Figures in the text have been prepared.

[APPENDIX.

APPENDIX.

TABLE I.—RESULTS OBTAINED ON TREATING STARCH-PASTE WITH PUTRID SEWAGE FOLLOWED BY AEROBIC FILTRATION.

Number.	Sample.	Calculated Strength.[1]	Cupric Oxide reduced after Inversion per 100 Cubic Centimetres.	Dextrose equivalent of CuO.	Rotatory Angle (200-Millimetre Tube).	Dextrin by Difference.	Ratio of Dextrin to Dextrose.	Total Solids. Mineral.	Total Solids. Volatile.	Chlorine.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates and Nitrites.	Remarks.
			Grams.	Grams.	°	°		Parts per 100,000.						
1	Starch-paste (10 lbs. starch to 50 lbs. water)	2 per cent. starch added = 1·6 per cent. calculated on dry starch .	2·60	1·2	1·76	0·10	$\frac{1}{12}$	..	..	..	..	..	..	..
2	Mixture of starch and sewage-sludge, after standing 1 day .	1·58 per cent. starch added = 1·26 per cent. on dry starch . .	2·40	1·1	1·65	0·09	$\frac{1}{12}$	..	..	..	..	..	..	..
3	Same after standing 5 days	..	1·03	0·47	0·88	0·08	$\frac{1}{6}$	140[2]	700	..	2·34	0·16	..	..
4	Filtrate I. (1st time) .	..	0·19	0·09	0·44	0·08	1	150	202	8·0	0·032	0·16	1·0	Slowly passed through 3-foot filter once.
5	Filtrate II. (2nd time) .	..	0·08	0·037	0·15	0·03	1	140	72	8·5	..	0·15	0·5	" "
6	Filtrate III. (4th time) .	..	0·01	0·005	..	..	..	130	34	8·5	..	0·120	Nil	" "
7	Filtrate IV. (5th time) .	..	..	..	..	..	..	153	41	10·0	..	0·116	Nil	" "
8	Figures for (7) calculated on chlorine, 8 parts	..	..	..	..	..	..	112·4	32·8	..	..	0·093	..	..

[1] Gelatinization not complete. [2] Slightly acid reaction.

TABLE II.—RESULTS OF EXAMINATION OF SAMPLE OF KIER-LIQUOR FROM THE WORKS OF MESSRS. STANNING & SON, LEYLAND, AND OF THE SAME AFTER TREATMENT.

(Parts per 100,000.)

Nature of Sample.	Date.	Dissolved Solids.			Suspended Solids.			Albuminoid Ammonia.	Oxygen absorbed.		Chlorine.	Nitrogen as Nitrates and Nitrites.	Alkalinity (Cubic Centimetres of Normal Acid required per 100 Cubic Centimetres).	Remarks.
		Mineral.	Volatile.	Total.	Mineral.	Volatile.	Total.		3 Minutes.	4 Hours.				
Raw liquor	July, 1900	570	360	930	1·6	2·0	3·6	..	..	..	38·4	..	8·6	..
Mixture (8 parts of kier-liquor to 1 part wet sludge) after standing 1 week	..	530	350	880	26·0	66 0	92·0	4·08	14·5	105·2	35·1	..	5·8	Ammonia and oxygen absorbed estimated on clear liquor.
Filtrate. .	..	450	231	681	3·6	1·8	5·4	0·160	0·6	2·24	37·4[1]	37·2	Neutral	Passed through 8 foot filter three times.
Filtrate from mixture after standing 2 weeks . .	..	480	204	684	..	..	..	0·120	1·08	2·02	38·3	34·8[1]	Neutral	,,

[1] Original volume maintained by addition of tap-water.

TABLE III.—RESULTS OBTAINED ON TREATING BLEACH- AND DYE-WORKS WASTE WITH PUTRID SEWAGE, FOLLOWED BY AEROBIC BACTERIAL FILTRATION, AT MESSRS. PEEL, TOOTAL & CO.'S WORKS, ACCRINGTON.

(Parts per 100,000.)

Date.	Nature of Sample.	Dissolved Solids.	Suspended Solids.	Albuminoid Ammonia.	Remarks.
30 January, 1901	Raw liquor and sewage . .	180·1	40·9	0·532	After standing 24 hours.
	Tank effluent .	98·7	3·7	0·615	..
	Filter effluent .	87·3	1·2	0·16	Clear and colourless.
30 January, 1901	Raw liquor .	148·3	155·8	0·210	Coloured.
	Raw liquor and sewage . .	198·0	30·7	0·431	After standing 24 hours.
	Tank effluent .	122·3	11·7	0·571	..
	Filter effluent .	76·6	1·1	0·142	Clear and colourless.
1 February, 1901	Raw liquor .	172·3	84·3	0·221	Coloured.
	Raw liquor and sewage . .	201·5	35·1	0·49	After standing 24 hours.
	Tank effluent .	129·4	8·9	0·582	..
	Filter effluent .	82·6	1·4	0·116	Clear and colourless.

TABLE IV.—RESULTS OBTAINED ON TREATING MIXTURE OF CRUDE (OLD) BEER AND SEWAGE ON A BACTERIAL FILTER (SPRINKLED).

(Parts per 100,000.)

Number.	Sample.	Cupric Oxide reduced per 100 Cubic Centimetres.	Maltose calculated on Cupric Oxide reduced.	Rotatory Angle (200-Millimetre Tube).	Dextrin by Difference.	Ratio of Dextrin to Maltose.	Total Solids.		Total Suspended Solids.	Free Ammonia.	Albuminoid Ammonia.	Chlorine.	Remarks.
							Mineral.	Volatile.					
1	Crude beer	0·519	0·377	4·4	0·73	1·9 to 1·0	247	3032·0	690	..	..	..	..
2	Mixture of beer and sewage sludge (⅓ volume wet sludge) after standing 5 days.	0·279	0·202	2·3	0·37	1·8 to 1·0	202	1458·0	254	16·2	8·0	..	..
3	Filtrate I, after filtering 1st time	0·095	0·069	0·66	0·101	1·4 to 1·0	186	424·0	..	2·9	3·12	10·0	Passed twice through 3-foot filter slowly
4	Filtrate II, after filtering 2nd time	0·071	0·033	..	..	..	182	288·0	..	0·72	2·35	10·4	„ „
5	Filtrate III, after filtering 3rd time	0·015	0·007	..	..	..	188	116·0	..	0·320	1·09	11·2	„ „
6	Filtrate IV, after filtering 4th time	..	..	..	..	..	186	94·0	..	0·24	0·80	12·0	„ „
7	Figures for (6) calculated on chlorine 10·0 parts .	..	..	..	..	..	155	78·2	..	0·20	0·66	..	
8	Final filtrate (5th time) .	..	..	..	..	..	250	85·0	..	0·08	0·177	16·4	„ „
9	Figures for (8) calculated on chlorine 10·0 parts .	..	..	..	..	..	152	52·0	..	0·05	0·108	..	

TABLE V.—RESULTS OBTAINED FROM TREATMENT OF WASTE FROM THE HOOK NORTON BREWERY, BANBURY.

(Parts per 100,000.)

No.	Sample.	Date.	Proportion of Waste to Sewage.	Chlorine.	Albuminoid Ammonia.	Oxygen Absorbed.		Nitrogen as Nitrates and Nitrites.	Oxygen Dissolved. Cubic Centimetre per Litre.	Gallons treated per Square Yard.	Time in Tank Hrs	Remarks.
						3 minutes.	4 hours.					
1	Filtrate . . .	1900 June 7	5 per cent. by volume wet sludge	..	0·285	1·05	4·04	..	0·74	600	..	
2	Filtrate . . .	June 7	,,	..	0·160	1·64	2·34	2·15	0 84	300	..	
3	Waste and sewage	June 18	,,	5·8	1·10	3·1	8·1	..	..	..	..	Depth of filter 8 feet.
4	Filtrate . . .	June 18	,,	5·4	0·16	1·2	2·9	0·5	0·20	770	48	
5	Waste and sewage	June 28	,,	5·7	1·00	4·79	12·07	..	..	..	..	
6	Filtrate . . .	June 28	,,	5·5	0·228	1·18	3·7	Trace	..	800	48	
7	Waste only . .	July 18	,,	8·8	1·32	28·5	184·5	..	..	..	48	
8	Filtrate . . .	July 18	,,	8·4	0·272	1·18	7·7	..	..	800	..	
9	Waste only . .	Aug. 31	,,	4·4	0·550	2·18	8·91	..	..	300	48	Clear portion only.
10	Waste and sewage	Aug. 31	,,	4·0	0·420	1·48	4·87	..	..	300	48	Clear portion only.
11	Filtrate . . .	Aug. 31	,,	4·8	0·084	0·21	1·91	1·44	..	300	48	Dissolved oxygen 5·68 cubic centimetres per litre after ½ hour's saturation; 4·8 cubic centimetres after 2 hours'; 4·37 cubic centimetres after 24 hours'.
12	Waste only . .	Sept. 25	,,	4·6	0·528	0·95	3·5	..	..	300	48	Clear portion only.
13	Waste and sewage	Sept. 25	,,	4·8	0·640	1·2	4·6	..	..	300	..	Clear portion only.
14	Filtrate . . .	Sept. 25	,,	5·4	0·120	0·31	1·8	1·10	..	300	..	O_2 after ½ hour's saturation, 5·07; 2 hours' standing, 4·05; 24 hours' standing, 3·5.

TABLE VI.—RESULTS OBTAINED ON TREATING PAPER-WORKS WASTE, AFTER SETTLEMENT, ON BACTERIAL FILTERS AT THE WORKS OF MESSRS. WIGGINS, TEAPE & CO., CHORLEY.

(Parts per 100,000.)

Sample.	Date.	Albuminoid Ammonia.	Nitrates.	Dissolved Solids.			Suspended Solids.		
				Mineral.	Volatile.	Total.	Mineral.	Volatile.	Total.
Unfiltered liquor	September 4th, 1900	0·124	..	41	21	62	..	..	..
Filtrate		0·054	..	47	14	61	..	..	..
Unfiltered liquor	„ 11th, „	0·134	..	39	17	56	..	..	..
Filtrate		0·096	..	36	14	50	..	..	..
Unfiltered liquor	„ 18th, „	0·285	..	43	14	57	2·8	4·4	7·2
Filtrate		0·160	..	36	14	50	2·0	1·4	3·4
Unfiltered liquor	„ 17th, „	0·266	..	46	17	63	3·6	3·0	6·6
Filtrate		0·208	..	40	17	57	1·6	2·4	4·0
RESULTS AFTER ADDITION OF SEWAGE TO PRECIPITATION-TANK.									
Unfiltered effluent	October 12th, 1900	0·180	..	..	..	..	2·7	5·4	8·1
Filtered „		0·072	1·1	..	..	..	0·9	0·3	1·2
Unfiltered „	„ 22nd, „	0·276	..	..	..	..	3·5	5·6	9·1
Filtered „		0·127	1·3	..	..	..	0·7	0·7	1·4
Unfiltered „	„ 24th, „	0·270	..	..	..	..	4·3	7·2	11·5
Filtered „		0·127	1·2	..	..	..	0·8	0·5	1·3

Discussion.

The PRESIDENT, in moving a vote of thanks to the Authors, explained that, as Mr. Davis was in Australia, he would ask Mr. Darley to say a few words on his behalf. Mr. Naylor was present, and would be able to supplement his Paper with any remarks he might consider necessary. The President.

Mr. C. W. DARLEY remarked that although, owing to the length of Mr. Davis's Paper, it had not been possible to read the whole of it, enough had been read to give those present an idea of the extent and importance of the scheme, which embraced really nine distinct schemes with twenty-nine separate drainage-areas, from which the sewage had to be collected and pumped to the summit of the main sewers. Such an intricate system was necessitated by the very uneven contour of the ground on which the city was built. At the time of the passing of the Sewer Acts nothing had been decided as to how the works were to be managed. The Metropolitan Board of Water-Supply and Sewerage had been subsequently instituted to take charge of the whole of the waterworks and the sewerage-works. It had been impossible to hand the matter over to any corporation, seeing that the area embraced no less than forty-four municipalities. The Board collected the revenue, not only for the waterworks but also for the sewerage. The Public Works Department constructed only the main works, all the reticulation-pipes and branch sewers being laid by the Board; and as soon as they were laid householders were compelled to connect, or else the Board stepped in and connected, and made a charge on the property for so doing. One peculiar feature of the works was the immense number of storm-water channels. No less than 30 miles of storm-water channels had been constructed, and in this respect work had been done to the value of £280,000 more than had been contemplated in the original scheme; the expenditure had been necessary in the interests of public health, to remove stagnant water from the irregular creek-beds. The storm-water channels were in nearly all cases useful adjuncts to the sewers, in taking storm-water overflow and thus preventing surcharging; and during heavy rainfalls they obviated frequent flooding and destruction of property. When the storm-water channels were first constructed, the Board was authorized to collect the rates, and levied a rate of *7d.* in the pound on a proclaimed drainage-area. Mr. Darley.

Mr. Darley. That ceased as the sewers were completed, so that eventually they would not be productive of revenue. Another important feature was the very thorough system of ventilation which had been carried out. There were about 460 miles of sewers under the control of the Board, with four thousand ventilation-pipes, practically nine pipes per mile. Of the four thousand, about two-thirds were exhaust and about one-third induct, and in both cases they were frequently helped by water-sprays. The vent-pipes ranged from 6 inches up to 24 inches in diameter, being mostly 6 inches and 9 inches. On an average about 236 million cubic feet of air was exhausted from the sewers of the city every day, and about 130 million cubic feet was forced in. Before the completion of the system the sewers had been damp, slimy and unhealthy, but it was remarkable how dry and healthy they had become as thorough ventilation had been extended. The Board had two staffs of men, one engaged on the water-supply, laying or taking up pipes in the streets, and the other engaged in sewer-work. The regulations of the Board provided that any man engaged in sewer-work who fell ill through no fault of his own received full pay all the time—of course under the certificate of the Board's medical officer. The men engaged in water-supply work, however, when ill lost time. The curious fact was that there was a much larger percentage of men ill who worked in the streets than of men working in the sewers.

Mr. Naylor. Mr. Naylor explained that his Paper had been framed and presented about nine months previously, at which date comparatively little had been done in the matter it dealt with. Since then much more had been done, and much more was known about the subject generally; and as far as his experience went, it only confirmed what was said, perhaps rather emphatically, in the Paper.

Dr. Rideal. Dr. S. Rideal considered that the Institution was indebted to Mr. Naylor for bringing before it the actual results of practical working with trades refuse on a large scale, especially as Mr. Naylor's official position as Inspector of the River Ribble made him a very critical judge. If the different manufacturers in the Ribble district had produced by bacterial methods effluents which were satisfactory to Mr. Naylor, it meant that considerable progress had been made. At the same time, most of the work mentioned in the Paper had been known to some for many years. The Author had confirmed the view which he himself held, that if the proper sequence of bacterial processes was adopted, practically all kinds of organic matter would break down and give satisfactory effluents. By proper sequence he

Dr. Rideal.

meant, not the method adopted five or six years ago, following the work of the Massachusetts Board of Health, of attempting to effect the whole decomposition in a contact-bed, but the realization of the absolute necessity of bringing about a preliminary decomposition of an anaerobic character before passing the liquid into a filter-bed where it was under oxidizing influences. That was seen very markedly in several of the experiments recorded in the Paper. With regard to the starch-paste experiments, all chemists were well aware that complex carbohydrates were capable of being broken down into carbohydrates of simpler constitution by a process of hydrolysis which did not involve any oxidation at all. But that inversion or hydrolysis required time and suitable conditions, and one of those conditions was not the presence of oxygen. It was seen clearly from the experiments in the Paper that the cellulose liquids which had caused a great deal of nuisance in many districts, when allowed to stand by themselves with the proper ferment, produced by mixing them with some anaerobic sewage, underwent a considerable breaking down into these simpler carbohydrates, which were then easily oxidized in the final stage. Another point brought out clearly was that the effect of the decomposing-tank or preliminary anaerobic decomposition was sometimes to augment very considerably a figure by which both engineers and chemists in the past had set great store, namely, the albuminoid ammonia. In Table III. the liquid from the tank gave in every case a higher figure for the albuminoid ammonia than the liquid which had been put into the tank; in other words, the preliminary process had caused an increase in the albuminoid ammonia. Therefore, as he had contended on previous occasions, an arbitrary standard of albuminoid ammonia must not be set up, because here was a process going on in the direction of purification, but involving in every one of the experiments an increase in the albuminoid ammonia. Another point of interest was the possibility of dealing, by bacterial action, with liquids containing chlorine. He had studied some of the electrolytic processes, and had found that chlorine had a marked sterilizing effect only when the organic matter had been practically removed by some preliminary bacterial process; and then very good sterilization could be produced. Bacterial treatment was therefore consistent with the presence of chlorine in those cases in which this absorption of free chlorine by some of the organic matter first took place. Free chlorine was also removed in another way prior to bacterial decomposition—he thought it had been so removed in

Dr. Rideal. some of the Author's experiments—namely, in the presence of ammonia. Free ammonia re-acted with chlorine very quickly, a neutralization was effected, and the germicidal properties of the free chlorine were in this way removed. Therefore a liquid containing free ammonia as well as free chlorine quickly reached a state in which it was amenable to bacterial change.

Mr. Latham. Mr. GEORGE B. LATHAM remarked that he was disappointed at the low efficiency of the electrically-driven pumps shown in Table IX. of Mr. Davis's Paper. He looked to electrical pumping as the method of the future for substations in a scheme of sectional pumping. He noticed that the efficiency under the most favourable conditions—which he presumed were ordinary working-conditions, and for which the pumps were designed—was in no case higher than 56 per cent. and, in one instance, as low as 39 per cent. Taking the efficiency of the motors as that given for driving the air-compressor, namely 87 per cent., and allowing a loss of efficiency for the pump of 20 per cent., would give a joint efficiency of 70 per cent., and he would have expected, allowing for all loss, at least an efficiency of 60 per cent. He wished to have some explanation of the cause of that low efficiency. Further, he could not clearly understand how the quantity of sewage pumped by the ejectors was arrived at. It was stated in the Paper that the number of times the ejector was discharged was noted, and in Table X. the capacity of the ejector was given in round figures in gallons. He would like to know whether the amount the ejector lifted was taken as equal to its actual capacity or was measured. If the former was the case, as might be inferred from the approximate figures, no allowance being made for slip, the resultant efficiency for the installation would be, as he would expect to find it, considerably lower than 34·8 per cent. It was interesting to compare the allowance made in the sewers for rainfall with the amount required in England. He considered that the usual practice of stating the allowance made for rainfall in inches, meaning inches in 24 hours, was misleading, and that the rate of fall would be better expressed in cubic feet per acre per minute, as it was the rate at which rain fell, and not the quantity, that determined the provision that must be made. Observations on the rate at which rain fell, taken at Croydon and extending over many years, showed that the average rate was equivalent to 1·56 inch in 24 hours, or nearly 4 cubic feet per acre per minute, 1 inch in 24 hours being equivalent to 2·5 cubic feet per acre per minute. Owing, however, to deferred flow, the provision for

1·2 inch in 24 hours or 3 cubic feet per acre per minute, made at Sydney, would be a reasonable provision in this country. In the scheme under discussion it was important to see not only what provision was made in the sewers, but what dilution of the sewage took place before the overflows came into operation. From the figures he noticed that before they came into operation the sewage would be diluted to eight times the average dry-weather flow, which was a very good allowance. Mr. Latham.

With regard to the second Paper the neutralization of the acid sewage containing galvanizing pickle by lime, and its subsequent passage through contact-beds, had been tried at Bilston, and the result had been satisfactory. He had also attempted the decomposition, without addition of chemicals, of sewage containing a large percentage of tannery-refuse, but had not yet obtained any satisfactory result.

Mr. A. Hanssen considered that the Paper on the sewerage of Sydney was a most interesting one, as the Author had had to deal with an area which was exceedingly difficult to drain, being very hilly and intersected with valleys; and there was a great deal of water in the district. While most of the sewage gravitated to the various outfalls, part of it had to be pumped: for part of the pumping Shone ejectors had been adopted, but for the greater portion electric pumps. Not only the pumps but the air-compressors also were driven by electricity, which appeared to be a somewhat roundabout and expensive way of driving air-compressors, because the work of an air-compressor fluctuated considerably during each stroke, while the action of the electric motor was uniform; and 1¼*d.* per Board-of-Trade unit was still a high price compared with direct steam-driving, except for very small powers. He did not think it was a satisfactory way of driving an air-compressor, though it had the great advantage that it was easy to measure the actual power used in lifting sewage. The trial carried out by the Author, with great care, showed that the Shone ejector under the circumstances had a useful efficiency of 34·8 per cent. for a lift of about 45 feet. He had made similar tests under similar circumstances, and had sometimes obtained a higher efficiency, such as 42 per cent. or 43 per cent. In some tests carried out at Chester many years ago by Professor Unwin, the efficiency had been still higher. He might mention, in reference to Mr. Latham's question as to the capacity of the ejectors, that in the tests carried out by Professor Unwin the capacity had been measured very carefully; and it had been found to be very nearly the same as the nominal capacity of the ejectors, being within 0·64 per Mr. Hanssen.

Mr. Hanssen. cent. The ejector was a good water-meter, in fact it was very difficult to get anything more exact than an ejector for measuring water. The stroke was very regular, and the fluctuation was limited to 1 per cent. or 2 per cent. He thought that the figures in the Paper might be taken as substantially correct in regard to the quantities of sewage lifted. The ejectors were rather small: a 50-gallon ejector had almost as much clearance-space as a 500-gallon ejector, and therefore with large ejectors the efficiency would probably be somewhat higher. With regard to the trials with electric pumps, he did not think the Author had taken the members quite as much into his confidence as he had done with ejectors, and it was difficult to see what the efficiencies meant. The Author spoke of "combined efficiencies of motors and pumps," which seemed to indicate that the figures were merely the combined mechanical efficiency of motor and pump, without reckoning what water actually entered the pump, or the loss in transmission: he also called the pumps "plunger-pumps," but judging from the dimensions of the plungers, 19⅜ inches and 13⅞ inches, they seemed to be plunger-and-bucket pumps and not merely plunger-pumps. They ran at a comparatively high speed, 48 revolutions per minute, and the motors ran at as much as 720 revolutions per minute. He thought it was a very risky thing to put machinery of that description in a damp underground chamber, where the pumps could not be looked after. Pumps working at 48 revolutions, with an annular space around the bucket of only 1½ inch, seemed extremely unsuitable for sewage. He was not aware that sewage had been pumped with pumps of that description on the sectional system; but pumping sewage on the sectional system was a different thing from pumping it at a large outfall, in which case the sewage had been immersed in large volumes of water in the sewers for many hours, and had travelled for a considerable distance. In the sectional system the sewage was in the sewer sometimes only for two or three minutes, and the sewers being small it floated on 2 or 3 inches of water. The solids contained in the sewage were not dissolved, and they came to the pump in practically the state in which they left the houses. If a screen was interposed, these solids were caught by the screen, and a man was needed to continually rake it clear. That was inadmissible where so many pumping-stations were working together. In order to pump sewage on the sectional system it was necessary to have apparatus which worked without a screen, taking anything that passed through the valves and sending it out again as the ejector did. He did not think the electric pumps described

Mr. Hanssen.

by the Author would be able to do that, nor did he believe that nearly as high a total efficiency would be obtained with them as with the ejectors. In a recent volume of the Proceedings, Mr. N. Maughan had given an interesting account of the main drainage of Woking.[1] There hydraulic pumps were used with large plungers working very slowly. The sewage, after being stored for some hours, was pumped without any difficulty, and the system was a close approach to an ejector. But the efficiency was not so high as that given in Mr. Davis's Paper for ejectors. The efficiency at Woking was not stated directly, but it was mentioned that 8 gallons of pressure-water raised 1,000 gallons of sewage through 1 foot. With an efficiency of 75 per cent. for the engine and pump it would be found that 52,200 foot-lbs. would lift 10,000 foot-lbs. of sewage. That gave a total efficiency of 19·2 per cent.,[2] which was very much lower than the ejector would give. For a higher lift he admitted it would give a better efficiency, but the lift at Woking was only 16 feet.

Sir A. Binnie.

Sir ALEXANDER BINNIE observed that it was usual to commence any remarks upon a Paper by paying a compliment to the Author; but on the present occasion he had to reverse that procedure, and to pay a compliment to the Institution on receiving so admirable a Paper as that on the sewerage of Sydney. He did not think the Institution had ever received so comprehensive a Paper as the one under discussion. A glance at the map would show the difficulties with which any engineer would have to deal in considering the question of the proper drainage of Sydney. The engineers connected with the work had proceeded on lines of the broadest catholicity. They had been hampered by no prejudices in favour of a particular system or systems, but had adapted their ideas to the circumstances by which they were surrounded. Some of the works dealt with in the Paper were simple gravitation works, by which the sewage was discharged in its crude state into the ocean, with a tide that prevented any harmful effect. There were more complicated cases arising inland, where there were sewage-farms, and the sewage was treated on land; and there was

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[1] Minutes of Proceedings Inst. C.E., vol. cxliv. p. 295.

[2] The pressure-water is lifted 28 feet, the accumulator pressure is 200 lbs. per square inch, therefore

$$\text{Efficiency} = \frac{(1{,}000 \times 10)\text{ lbs.} \times 1\text{ foot}}{\left(\frac{(8 \times 10)\text{ lbs.} \times (200 \times 2\cdot307 + 28)\text{ feet}}{0\cdot75}\right)} = \frac{10{,}000}{52{,}200} = 19\cdot2\text{ per cent.}$$

Sir A. Binnie. chemical precipitation, and the septic tank combined with precipitation. Not only were there gravitation systems, but there were numerous instances where pumping could not be avoided. The problem had been faced by the adoption of various expedients, and by the introduction, almost for the first time in sewerage questions, of electric pumping and electric control of air-compressors. He was not inclined, as the last speaker had appeared to be, to throw cold water upon an effort of that kind, because he believed that in the future, where power had to be distributed to many distinct outlying stations, electricity offered perhaps the cheapest mode of transmitting it. After studying the Paper very carefully he was bound to say he did not find anything to criticise. It was a model Paper which all the younger members might well copy, having regard to the diversity with which the subject was treated, and the fairness with which views that, he was afraid, engineers were in the habit of considering somewhat antagonistic, had been combined in producing a result which, judging from the statistics in the Paper, must be most gratifying to the authors of the scheme.

Turning to the second Paper, and coming nearer home, the effort now being made to dispose of trades refuse in the great manufacturing towns ought undoubtedly to receive the support of every one. He had been studying the question of the bacterial treatment of sewage for some years past, and was aware that such treatment could produce wonderful effects. By a judicious course of precipitation and bacterial treatment it was possible in sewage to reduce the dissolved solids—and they were really the great hindrance—by 80 per cent.; but the effluents which flowed from manufactories were not so easily dealt with. Some people considered that the chemical constituents killed the bacteria. In a certain sense they did, and it was by skilful treatment of the waste liquors from the manufactories in the first instance, that they were reduced to a state which enabled bacterial life to flourish, and to produce such effluents as those mentioned in the Paper. Of course the method of treatment described by the Author was not one that could be applied, on any large scale, to town sewage; and no doubt the Author would be one of the first to acknowledge that its special value was in connection with the subject of river-pollution, with which the Paper dealt more particularly. In the large districts of Yorkshire the rivers were polluted by trades refuse, and it could only be hoped that the suggestions and the examples which had been set forth in the Paper might bear fruit even in a larger field.

Mr. Bertram Blount considered that it was his province to speak exclusively on the second Paper, but he would offer a remark on one point connected with the first, which interested him as a chemist; namely, about the air-compressor, an apparatus employed frequently in all kinds of chemical manufactures. If there existed a badly-contrived apparatus of an engineering kind it might be said to be the air-compressor, and speaking as a chemist, he would like to see it abolished. Not being content with purely destructive criticism, he proposed a remedy which might commend itself to those more learned in such matters. He thought an apparatus on the lines of the Parsons turbine, in which the air would be taken in at a low pressure and gradually screwed up to a high pressure and sent out in a continuous stream, might be useful. Mr. Blount.

With regard to the Paper on the treatment of trades waste, Mr. Naylor was entitled to be listened to with all respect. He thought the fundamental note of the communication was the Author's realization of what might be termed the manufacturer's real difficulties. The manufacturer was intent on producing goods of all kinds which had to be turned out at a moderately low cost, and he naturally objected to anything which offered no immediate prospect of profit. If he could obtain fairly pure water, use it in his business, foul it to any degree, and turn it loose upon the community, he was quite content. The community, however, had different views, and such investigators as the Author could show the manufacturer how to prevent the nuisance, and could make his path much easier. The refuse from quite a number of different trades had been examined by the Author, and among them, trades the waste of which was very troublesome to treat. The one he had specially in mind was the effluent from the woollen industries. No more objectionable effluent could well be conceived, and owing to the great prosperity of that trade at one time there had been perhaps more reluctance to save what was on the whole a valuable product than would be expected if the question were examined in the light of cold figures. He had estimated the loss incurred in turning the greasy materials into the streams, and had found that there would be an abundant margin of profit for an enterprising manufacturer who would recover the grease. At present it was recovered in some cases, but always in a half-hearted way; and the great majority of manufacturers made no attempt to recover it at all. When, at the instance of skilled persons like the Author, a little kindly and judicious pressure was brought to bear on manufacturers, they

Mr. Blount. discovered that what they had been doing for so long was not merely unnecessary, but was to their own disadvantage, and they then proceeded on different lines altogether. The Paper did not give any specific directions for the treatment of the waste he had mentioned, but it gave very clear directions for the treatment of other trades waste, and if the Author were to turn his attention, as doubtless he would, should opportunity arise, to the handling of the noxious woollen-trades refuse, he would find little difficulty in inducing manufacturers to regard the whole problem in a more reasonable light than they had hitherto done. Taking another instance, which was not quite so bad, although quite bad enough, he noticed that the Author had paid considerable attention to brewery-waste, and had found that it could be handled in a thoroughly satisfactory manner at a reasonable cost. As to the chief reason of the success of the experiments, it was possible that it resided in two causes. First, there was the handling of each trades waste separately and on its merits. In embarking upon the purification of the refuse from a given trade it was futile to lay down general rules that might be applicable to domestic sewage. Such sewage did not vary very much in character, for although there might be differences in the degree of concentration and the like, the nature of the stuff was the same: but trades refuse was different, and each effluent had to be considered by itself, not merely the effluent of each trade but the effluent of each works; and consideration could best be given to it by the man on the spot. The second and equally obvious cause of success was the very reasonable method adopted by the Author in impregnating with some active organism the organic material which he hoped to ferment. Sewage-sludge was used, a material which was always at hand, whose activity was known; and if the low organisms present could be induced to grow in the pabulum provided for them, the resolution of the solids in solution was insured. That was equivalent to inducing fermentation in beer by "pitching" a wort with yeast of a determined kind. The waste at Messrs. Peel, Tootal and Company's works was a difficult waste to deal with; and as it seemed to have been handled with success, he would like to know how long the plant had been at work and particularly whether any choking of the filters had occurred.

Prof. Unwin. Professor W. C. Unwin remarked that one problem recurred frequently to which he had had to give occasional consideration, namely, the problem of dealing with the sewage of districts situated at very low levels, which had to be pumped. There

Prof. Unwin.

were several ways of dealing with cases of that kind, such as collection of the sewage by a deep-level sewer into a central station and pumping, or the distribution of pumping-stations over the district. The first really successful plan for dealing with low-level districts of that kind in the latter way had been that of pumping by ejectors worked by compressed air, some of which were used in Sydney. Several years ago he had had the opportunity of testing ejectors of that kind very carefully indeed under conditions in which exact measurements could be made, on lifts not widely differing from those at Sydney. The ejectors, however, had been of larger size, and the efficiency obtained had been considerably better than the efficiencies given in the Paper. He did not see why the injector should be at all an inefficient pump. In using a system of that kind it was always necessary to include the inefficiency of the compressor; that inefficiency was unavoidable and increased with the height of the lift. In certain districts at Sydney a quite novel system of dealing with distributed pumping had been introduced, the system of having reciprocating pumps worked by electric motors at various stations and controlled from a common centre. That method was exceedingly interesting, and in certain cases, especially where the lift was greater than that which was specially suitable for an ejector, electric pumping would become a very important means of dealing with low-level districts. But he protested against the use in any way of reciprocating pumps driven by electric motors. The evil was greatest where such a material as sewage had to be pumped, especially where in distributing-stations of that kind the pumps were of large size, and where the problems of the valves and similar difficulties must, in the long run, prove to be a source of much trouble. The electric motor was a machine rotating at a high speed; the speed of a reciprocating pump had to be very low. In cases referred to in the Paper the speed was reduced in the ratio of something like 12 to 1 from the motor to the pumps, which in itself involved a very considerable loss of the energy of the motor. If electric motors were to be used for pumping, a centrifugal pump should be used. In the first place all valves were done away with, and the pump could be submerged in the sewage and be started by the rising of a float; and in that way would be obviated a good many of the troubles likely to arise with a system involving the use of reciprocating pumps. The ordinary objection to centrifugal pumps was, that they were inefficient. Nobody would hesitate for a moment to put in an

Prof. Unwin. inward-flow turbine and to guarantee, on any fall between 3 feet and 400 feet, an efficiency of 75 per cent. A centrifugal pump was simply an inverted inward-flow turbine, and there was no reason why the efficiency should not be guaranteed as the efficiency of an inward-flow turbine was guaranteed. The reason why in centrifugal pumps low efficiencies were often obtained was the want of sufficient scientific knowledge in the construction of such pumps, due principally to disregard of some of the essential conditions in which the centrifugal pump worked. He thought it would have been much simpler and more efficient in the long run if the motors had driven centrifugal pumps directly. It might be said that in Sydney there were lifts which were rather high for centrifugal pumps; but no one hesitated to use the turbine for any fall, and he himself had used inward-flow turbines for a fall of 400 feet. There was no reason why the centrifugal pump should not be equally applicable to high lifts. It had been shown lately by Messrs. Sulzer Bros., in Switzerland, that centrifugal pumps could be used on lifts of 400 feet and more with an efficiency of 70 per cent.[1] It was nothing but a question of constructing the pump properly, and he could not help thinking that, not only in the pumping of sewage, but in many cases of pumping where it was convenient to use electrically-driven pumps there was a field for an electrically-driven centrifugal pump. In fact, he looked to the use of centrifugal pumping in conjunction with the electric motor as being one of the things which would, before very long, come to be of considerable importance. In the pumps which had been erected in Switzerland for very high lifts there was nothing very special, and nothing, he thought, that was even patentable. They were constructed directly on the lines of the inward-flow turbine, and differed from the common centrifugal pump only in the fact that they had—as every turbine had—in addition to the rotating wheel, passages in which the kinetic energy of the water leaving the pump was properly utilized.

Mr. Roechling. Mr. H. A. Roechling remarked that he endorsed Sir Alexander Binnie's congratulation to Mr. Davis on the excellence of his Paper, and also on the results of the works carried out. It was very satisfactory to see the benefit which had accrued to public health from the system. In England, and in Europe generally, the lowering of the zymotic death-rate, and of the general death-rate

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[1] A Sulzer centrifugal pump at Geneva works efficiently on a lift of 140 metres.—W. C. U.

of a district, by systematic drainage and water-supply, was looked upon as an axiom, and it was interesting to know that similar results had attended such works in Sydney. The money spent had been well spent. It was mentioned in the Paper that the sandstone strata, probably belonging to the Trias, dipped westward; but it appeared to him that the dip might be southward. In that case the southern portions of the town would be drained on the dip slope, and the northern portion, draining into Port Jackson, would be drained on the escarpment area. The geological features of a site were always interesting; and there could be no doubt that in this instance disturbances which had taken place since the strata were laid down had greatly added to the difficulties of draining the place, and that might account for the considerable expense which the main drainage had involved. According to figures in the Paper, the cost at Sydney had been something like £8 per head of population. Comparing that with the cost of main-drainage schemes in Europe, in Dantzic the cost per head had been £1 6*s.*; in Paris, £2 2*s.*; in Hamburg, £2 7*s.*; and in Berlin, £2 17*s.*, that city having been drained on the radial system, which had involved some extra expense. London, with all its ramifications of sewers, had cost, according to the reports of the London County Council, only £3 7*s.* per head; Liverpool, £3 19*s.*; and Frankfort-on-Main, £4 12*s.* Practically, therefore, the cost at Sydney was at least double that of the most costly European systems; and it would be interesting if the Author could state what had made the cost so high. It might have been the very large allowance made for dry-weather flow, viz., 75 gallons per head with a water-supply of only 42 gallons; or it might have been the large allowance made for rainfall—up to 2 inches per day; but as no particulars of the rainfall were given, it was impossible to say whether the allowance was really so large as it appeared to be. It was open to question whether some portion of Sydney might not have been drained on the separate system, as there were nine separate drainage-areas, twenty-one or twenty-two pumping-stations, and four ejector-stations. He also wished to know how the concrete had stood in the main drains and sewers of Sydney, especially in treacherous ground. He had seen on the Continent a large sewer constructed of concrete collapse in very bad ground. The Paper did not deal with the question of sewage-disposal as fully as might be wished, having regard to the fact that at Sydney there was a sewage-farm, intermittent downward filtration, filter-beds, septic tanks, and contact-beds. It was gratifying to learn that the sewage-farm had Mr. Roechling.

Mr. Roechling. answered all expectations, that there was a fair hope it would pay its own way, and that it had not given rise to any nuisance.

The Paper on trades waste was a valuable one. The treatment of manufacturers' waste liquors was a difficult question to deal with and an urgent one in many districts. All endeavours to solve the problem—especially those made successfully, as the Author's appeared to be—deserved thanks, not only from the individual point of view, but from a national point of view. It was desirable not to lay upon manufacturers a greater burden in regard to the purification of their waste liquors than was absolutely necessary. Some of them were allowed to discharge their waste into the sewers, and others were not; and those who had to start purification-works for waste liquors had in some cases to pay not only for their own works, but also for the works of the general public. If it was possible to admit waste liquors into the sewers it would be a great boon to manufacturers, and in that respect he thought the Paper was especially valuable, as, according to the Author, the admixture of sewage with manufacturers' waste liquors was not to be avoided, but was desirable. If it was possible, through the admixture of sludge, to render the liquors amenable to treatment, a great advance had been made. There was one point on which he desired enlightenment, and that was the disappearance of free chlorine, or rather the disappearance of the disinfecting effect of chlorine. Chlorine was looked upon as a powerful disinfectant, as a destroyer of germs; but, according to the Paper, liquors containing free chlorine, and which in the first instance had a sterilizing effect, were amenable to bacterial treatment. The free chlorine must have disappeared at some stage in such a manner that it did not injuriously affect germ life, and he wished to know whether the Author considered that it was a chemical, a biological, or a bio-chemical process which resulted in the removal of free chlorine. The point was important, because if bacteria had power under certain conditions to destroy germicides, then the views held with regard to disinfectants would have to be considerably modified.

Mr. Martin. Mr. ARTHUR J. MARTIN also considered that the first Paper covered so vast a field, and that everything had been treated in so lucid a manner, with that absence of dogmatism to which a former speaker had referred, that there was very little left to say on the subject. With regard to the last speaker's comment on the high cost of the sewers per head, the same thing appeared to be observable with regard to purification-works. He noticed that the septic-tank installation at Rookwood had cost something

like £6 per head of population, whereas a similar installation in England could be laid down for probably one-fourth or one-third of that cost, depending on local circumstances. The discrepancy would not be accounted for—as possibly was the case with the sewers—by the volume dealt with, because the maximum quantity treated was only 50 gallons per head per day; and, although the tanks were a little larger than they would have to be to satisfy the English Local Government Board, the filters, on the other hand, were smaller than they would have to be for an equal population and flow in this country. Therefore the excess of cost was evidently due either to the style of construction, which did not seem to be extravagant, or to the cost of labour and materials in Sydney; and he ventured to think the latter was probably the cause. Perhaps some members present who had had experience of work in Australia, could answer that question positively. Mr. Martin.

With regard to the Paper on the treatment of trades waste, he thought the Author deserved great credit for the plucky way in which he had tackled waste liquors which were universally conceded to be the *bête noir* of engineers concerned with sewage-disposal. Galvanizers' pickle, for instance, and bleach-works waste were two substances which had always been held to be beyond the reach of bacterial treatment. The Author had undoubtedly struck the key-note of success in that class of work by introducing a strong culture of the organisms proper to sewage, namely, by adding to the liquid to be treated a certain amount of sewage-sludge; and his results had justified the means. He had had a good deal to do with manufacturers' refuse, but almost invariably in conjunction with sewage; and there could be no doubt that in the sewage of a large town such as Manchester or Leeds, although there were some particularly obnoxious trade-wastes to be dealt with, yet, in the condition which they were received at the outfall, their individual effects were to a large extent mitigated by their mutual reaction. In the case of a city such as Manchester there were many different kinds of trade refuse—some acid, some alkaline, some possessing other strongly-marked chemical characteristics—which to a certain extent neutralized one another before reaching the outfall. He did not gather from the Paper, as the last speaker apparently did, that there was an actual destruction of chlorine going on in the experiments, but merely that the chlorine which was present originally in such forms as hypochlorites and compounds of that nature, which were strongly bactericidal in their action, was changed by admixture with the

Mr. Martin. sewage and by certain reactions into chlorides and similar forms which were not bactericidal. The Author had one great advantage, and that was in the means which were at his disposal, not only for carrying out experiments, but for analysing the effluents in a systematic way. Information of the kind given in the Paper was of the utmost value to all who were concerned with the purification of such sewage, and he thought the members owed the Author a large debt of gratitude for what he had done in that direction. Most of his own work in connection with trade refuse had been done on town sewage in which such refuse was combined with ordinary sewage, and in which, therefore, the difficulty of dealing with it was greatly reduced. He might mention the case of Yeovil, where the sewage was highly charged with discharges from tanneries, leather-dressing works, slaughter-houses and breweries, and where no difficulty had been experienced in getting an entirely satisfactory effluent. However, in one case, in which he had had to deal with the waste water of a brewery without even closet-discharges, he had adopted the plan referred to by the Author of tipping into the tank a load or two of night-soil from an old cess-pool; and the effect had been very marked. The characteristic odour of decomposing brewery-refuse, in which he supposed lactic acid and similar compounds figured to a large extent, had been almost entirely absent, and the filtered material when dug up had not had that smell, but just the odour that would be given off by garden-mould or by any healthy bacteria-bed. That result he attributed, to a large extent, to the inoculation of the tank with the refuse from the cess-pool. In that instance the fall had been limited, and only a single filtration had been used. He would have liked to have two contacts; but, not being able to do so, he had adopted a plan which was the opposite of that recommended by the Author. Instead of concentrating the waste, he had diluted it, taking in as much clean water as possible; and by this means he had succeeded in getting a very fair effluent from brewery-refuse after a single contact.

Mr. Thrupp. Mr. E. C. Thrupp remarked, that if Mr. Davis's Paper was examined the reason for the adoption of electric power for pumping sewage was fairly evident. Generating-plant had been laid down by the Railway Commissioners to work a tramway, and they had offered to supply current for the use of the city authorities at the price of 1*d.* per Board-of-Trade unit: therefore it was not surprising that the engineers had taken advantage of the offer and had used electricity for the purpose of pumping sewage. Perhaps if they had had to generate the current them-

selves they might not have adopted that system. As to the valves of reciprocating pumps not being suitable for pumping sewage in sub-stations, he did not see why such valves could not be made similar to the valves of compressed-air ejectors. The ordinary simple plunger-pump, with an inlet suction-valve and an outlet constructed on much the same principle, was that which was usually adopted for sub-station pumping. He had had experience of such pumps driven by gas-engines, and they worked quite satisfactorily. With regard to compressors, he thought Mr. Blount had been rather hard on the ordinary compressor, and he did not think he would have been quite so hard if he had tried the alternative of a turbine, as he had suggested. The ordinary air-compressor with controlled valves was really not at all an inefficient machine, and he did not think a better result would be obtained by adopting the turbine. He was much interested in Professor Unwin's opinion as to the future of centrifugal pumps driven direct by electric motors, but did not quite follow the suggestion, because to put an electric motor underground, at such a level as to deal satisfactorily with the sewage, was rather risky. He had had some experience of putting electric motors underground in shallow chambers, and the difficulties of insulation, owing to the moisture condensed underground in certain states of the weather, had led him to prefer to put them above ground if possible. In pumping-stations for sewage an electric motor might be an excellent thing for driving a centrifugal pump, provided that pump was of the vertical-spindle type, when the motor could be kept high above the level of the sewage, possibly above the ground-line, and the pumps could still be kept sufficiently low to prevent any difficulties arising from the priming of the pump when starting. It would be an awkward thing to have a centrifugal pump situated some 10 feet above the level of the sewage, unless there were special arrangements or attendants at the sub-station, which it was desirable to avoid. The employment of electric motors for driving compressors for the air used to drive the ejectors, was another method of getting over the difficulty of having the electric motors underground, but he thought that it would scarcely be held to be an economical arrangement unless current were obtainable at 1*d*. per Board-of-Trade unit. Mr. Thrupp.

Mr. William Naylor, speaking on the first Paper, remarked that it was gratifying to the members of the Institution to know that their Colonial brethren were following on the old country's recognised lines and were placing some reliance on the work which was being done at home. With regard to Mr. Naylor.

Mr. Naylor. power, he did not agree with Mr. Thrupp that the air-compressor was anything but a badly designed and badly contrived machine. The very argument suggested by Mr. Hanssen strengthened the objections to it. Mr. Hanssen had objected to electrically driven compressors because the electric motor was regular in its action while the resistance of the air-compressor was not. But in a steam-driven air-compressor the conditions were even worse. The greatest power was in operation on the admission of steam, and it diminished to the end of the stroke, where the resistance was a maximum. The impetus or surplus energy available on the admission of steam had to be taken up by the fly-wheel, and the shock at the end of the stroke resulted frequently in either knocking the compressor off its bed or breaking the crank-shaft. Electrical driving overcame that in a measure; and if in addition a system of toggle levers was contrived which gave the power just where and when it was required, and recourse was had to the Ingersoll-Sargeant water-cooling apparatus or similar contrivances, a machine might be reached which would be good enough to worry along with. But even then it would be a bad one, and he thought some method might be devised for compressing air much handier than anything there was at present. Compressed air was a very convenient form of power. There was nothing in the Paper which suggested that the pumps, air-compressors and electric motors were in a dark damp chamber, nor did he see why they should be. There was no insuperable difficulty in making an underground chamber light, dry, and sweet.

Mr. Darley. Mr. C. W. Darley remarked that there were two points on which, in the absence of Mr. Davis, he might throw a little light. With regard to the heavy cost of carrying out the works in Sydney as compared with European work, the question was: Was the cost in Europe an inclusive one, covering the whole of the works, the ventilation of the sewers, and, in fact, everything? If so, the Sydney works appeared to be much more costly. Sydney was unique in the quantity of tunnelling required, there being over 100 miles of tunnel through solid rock at great depths. There were also costly shafts and much other expensive work. On account of the great damage done to house-property by using explosives for the tunnels, many miles had had to be driven by pick and gad, which had involved the payment of high wages, and had thus made the work extremely costly. The work had been done very largely by Italians, the only people who could be found to practically take their lives in their hands in carrying out the work, because the

loss of life, caused by the dry sandstone grit getting into the lungs, had been very considerable. Included in the cost were the 30 miles of storm-water channel, which was perhaps a unique feature of the works: that alone had cost £280,000. As to the use of electricity for compressing air to drive the Shone ejectors, from time to time a good many engineers had been connected with the scheme, which had been started by the late Mr. Bennett, who had laid out the main lines of the scheme and had carried out the chief portions of the northern and southern work. Then had come Mr. Hickson; and through subsequent departmental changes he himself had had control for about a year, when that point had cropped up. The Double Bay scheme had been worked out for the Shone system with steam-driven pumps. Double Bay was enclosed by hills on both sides, and the area contained very costly mansions and residences; and complaint had been made of the probable effect of the chimneys. In looking into the matter he had found that the Railway Commissioners were putting down an electric installation to drive the tramway in that locality, and it had occurred to him that that was one way of getting out of the difficulty; and so the system had really been determined by sentiment rather than by economy. Owing to this possibility of obtaining the power cheaply, the design of the house had been altered, a much smaller and cheaper engine-house had been constructed, and motors had been put in to drive the pumps. The electrically driven plunger-pumps had received a great deal of consideration by Mr. Davis. No great difficulty had been anticipated with regard to them, because for many years such pumps had been worked successfully by gas-engines on very crude sewage in Melbourne, without any trouble whatever. They were three-throw plunger-pumps with very large clearance and valves. He quite believed with Professor Unwin that centrifugal pumps might be used, but in this instance difficulties had cropped up, one of them being the re-charging of the pumps from time to time. The pumps had to work automatically, without attendance; and he knew from experience that unless they were very favourably located serious difficulties arose. If they were allowed to run the well dry the charge was lost, and often it was difficult to charge them again. The argument at the time had seemed to be in favour of plunger-pumps, and they had been adopted for the scheme. Mr. Darley.

Mr. Naylor, in reply, expressed his appreciation of the kind way in which his Paper had been received. It was very encouraging to him, and must be to the younger members, to see that Mr. Naylor.

Mr. Naylor. when anything new and even incomplete was brought before the Institution it received so kindly a reception. The Paper could not be said to be a complete exposition of the bacterial method of treating trades waste; it was a record of the results obtained on certain initial experiments. He had seen Mr. Blount rise with some trepidation, as he knew exception might reasonably be taken to many things in the Paper; but Mr. Blount and other speakers had taken the Paper for what it was worth, and instead of throwing cold water on it had encouraged others to persevere with the subject. Mr. Blount had an intimate knowledge of a great many paper-mills and chemical engineering works, both in the north and in the south of England, and Mr. Naylor could assert that once it became known among manufacturers that the methods described in the Paper did not receive any adverse comment from the gentlemen he had mentioned, they would be prepared to give it a thorough trial. Naturally they would not be prepared to accept these methods on the word of one man as willingly as when they were backed by the opinions of such experts as had spoken in the discussion. He was afraid Mr. Roechling had misread the Paper, or that the observations in it with regard to chlorine had been badly expressed. He did not mean to say that chlorine disappeared: any figure for chlorine given in the Paper was combined and not free chlorine. He would be sorry, too, to suggest that bacteria had the power of "destroying" germicides, but he thought Mr. Roechling meant "resisting" germicides. After all, the amount of chlorine even in bleach-works waste, which contained more than any other kind, was not large. The strength of the "chemick" used was only 98 grains per gallon, while Messrs. Roscoe and Lunt had shown that 0·05 per cent. to 0·1 per cent. was necessary to produce sterilization, and Messrs. Muspratt and Smith claimed for the disinfectant "chloros" that 0·05 per cent. would act as a germicide. When there were only 98 grains per gallon (0·14 per cent.) in the first instance, and it was remembered that some of this was used up in the process, and that what was left was diluted about fifty times, the chlorine could not be strong enough to act as a germicide. That was to say, chlorine would not be present in sufficient quantity to be left uncombined and fail to act as a sterilising agent: if it were, it must be kept out. That was the key-note of the matter. It was not possible to say that the problem of treating trades waste was solved by admitting it into the sewers. Mr. Roechling seemed to think that the result of the Paper would be that the local authorities would be prepared to receive the waste from manufactories into the sewers; but that

was not at all what the Author anticipated, and was not the drift of the Paper. Manufacturers' waste might be so manipulated, each waste being studied by itself, as to be amenable to bacterial treatment. It was going a long way farther than he had intended, to say that it would be admitted into the sewers directly. The effect of the filtered waste from Messrs. Peel, Tootal & Company's works at present was satisfactory. The filter was active and the effluent contained nitrates. It had not yet been discovered exactly how much sewage was necessary for a certain amount of the waste, and each case would have to be dealt with by itself. In the case in question an endeavour was still being made to put in the minimum amount of sewage to bring about a satisfactory result, because all superfluous sewage was really being purified uselessly. It was intended here to get a good effluent, even at the expense of dealing with a little more sewage than was necessary; but it was hoped that in the future the minimum amount required would be arrived at, viz., just sufficient to prevent souring and to keep the filter active, as evidenced by the presence of nitrates in the effluent. Mr. Naylor.

The PRESIDENT considered that the Paper on the sewerage of Sydney was well arranged, and agreed with Sir Alexander Binnie that it would form an example for other Papers. He concurred in Professor Unwin's remarks with respect to pumping. Although reciprocating pumps were very good things for pumping sewage, it was generally admitted that where electric motors were used, and as a consequence higher velocities were attained, the centrifugal pump appeared to be the proper pump to use. Some years ago, in using a centrifugal pump for pumping sludge, a difficulty had been experienced. The pump had not been running for many minutes before it had ceased to deliver sludge, and on opening it to find out the cause the stoppage had been discovered to be due to a lady's back hair, which had wound round the spindle until it had stopped the inlet. It had been cleared away and the pump had been set to work again, with a similar result in a very short time. A sleeve had then been attached to the gland, which covered the spindle and nearly touched the rotating part of the pump, and there had been no more trouble from this cause. A similar difficulty might arise where pumps were used for pumping sewage, though, having regard to the greater quantity of fluid passing through the pumps, it was not so likely to take place as in the case where sludge was being pumped. The President.

With regard to Mr. Naylor's admirable Paper, its Author was

The President. especially qualified to speak on the subject of the prevention of pollution by trades waste, because his professional avocations brought under his inspection a great many manufactories. But however desirable it was to prevent the pollution of streams, it was necessary to be careful not to harass the manufacturers to such an extent as to ruin their trade. Manufacturers often had but a small margin of profit, and were in competition with foreigners who were not subject to the restrictions which obtained in England. Happily the utilization of trades waste sometimes led to profit. An admirable instance of the profits arising from trades waste might be found in gasworks. In former days the tar and ammoniacal liquors had been got rid of as best they might be, with no thought of utilizing them. Now those refuse products were a great aid in lowering the price of gas.

*** Mr. Davis's reply to the Discussion will be found at the end of the Correspondence (p. 250).

Correspondence.

Mr. Bryce. Mr. J. BRYCE remarked that there was one question in connection with Mr. Davis's Paper which was of great importance to municipal engineers, viz., the capacity of storm-water channels. It was stated in the Paper that in Sydney the storm-water channels were designed to carry off a rainfall of 2 inches per hour, which was a much higher allowance than was adopted in Great Britain. The statistics of the rainfall for the district of Sydney did not appear to show a much higher rainfall than the average for Great Britain; but probably the excessive falls in short periods were heavier and more frequent. It would be interesting to learn from the Author the intensity and frequency of the heaviest rainfalls in short periods, and on what basis the storm-water channels had been designed to remove 2 inches of surface-water per hour. The general British practice seemed to be to provide for 50 per cent. of the rainfall reaching the storm-water overflows; but there were no reliable data, as far as he could find, on this subject. Perhaps American municipal engineers had done more than any others to investigate the relationship between rainfall and discharge, and Mr. H. N. Ogden, Assistant Professor of Civil Engineering in

Cornell University, in a work[1] recently published, endorsed the opinion of Mr. Emil Kuichling, City Engineer of Rochester, N.Y., that, as regarded the general practice in Great Britain, engineers had hitherto been content to rely on the results of experiments on the London sewers made between 1857 and 1865, and that it had come to be in some measure traditional to adopt 50 per cent. as the run-off from urban surfaces during the progress of a storm, while the remainder might follow at leisure. Mr. Ogden further showed that in American cities, from very careful observations carried out by municipal engineers, the percentage of maximum discharge ranged from 4 per cent. in rural to 58·2 per cent. in urban districts; and farther on in his book Mr. Ogden quoted the following statement by Baumeister[2]:— Mr. Bryce.

"In England from 0 to 70 per cent. of the fall reaches the drains, averaging about 50. In different districts of London from 53 to 94 per cent. has been registered. It required from 3 to 4 times the duration of the rain to carry off the water, and the maximum flow per second in the sewers rose as high as 2·4 times the average obtained by dividing the total effluent due to the storms by the number of seconds flowing. Hence it will be seen that the necessary capacity will be $0 \cdot 5 \times \frac{2 \cdot 4}{3 \cdot 5} = \frac{1}{3}$ of the rainfall per second."

He thought that if Mr. Davis could furnish any information as to the relation of the intensity of the rainfall to the discharge during the period of the fall, the maximum discharge per second from urban and rural areas, and the relation of the discharge to the slope of the drainage-area, it would be a valuable contribution to the subject.

Mr. W. E. Cook remarked that Mr. Davis, in his tabulated statement at p. 122 and in Table IV. of the Appendix to his Paper, scarcely made clear the allowances of sewage and rainfall which the northern and southern outfalls had been designed to discharge. For the northern system the proposal of the Board, endorsed by Mr. Clark,[3] had been the following:— Mr. Cook.

"The total area is estimated at 5,379 acres; that portion of the above from which the sewage and rainfall would be intercepted being 3,084 acres. From 1,183 acres, comprising portions of Woollahra and Waverley, it is proposed to intercept the sewage only. The capacity of the intercepting sewers is intended to provide for the discharge of $\frac{1}{4}$ an inch of rainfall for twenty-four hours, together with the sewage at the rate of 1 cubic foot per head of the population per hour."

[1] "Sewer Design." New York, 1899.
[2] "The Cleaning and Sewerage of Cities," p. 15. New York, 1891.
[3] "Report," &c., p. 8.

Mr. Cook. The area of 1,183 acres had then been so rural in character as to render provision for surface-water unnecessary. The drainage of the remaining 1,112 acres it had been proposed to discharge into the harbour at various points, as before. Mr. Clark had further proposed to provide for the sewage-flow only, from 75,000 persons in Petersham, Leichhardt, and Balmain, this flow to be received into the upper end of the proposed main outfall-sewer. With regard to the southern system, Mr. Clark in his report had said: "I would propose that in the extension of the drainage works to the southern area, the capacity of the sewers should be equal to 40 per cent. of 3 inches [of rainfall] per day, or one-twentieth of an inch per hour:" and the Author stated that this alteration had been adopted. Table IV. in the Appendix showed that in calculating the discharge on the northern system the proposal endorsed by Mr. Clark had not been carried out. This Table showed that an area of 7,769 acres had been dealt with, and that rainfall had been allowed for at the rate of ½ inch per day over the city area of 1,692 acres; while over the remaining 6,077 acres the rainfall allowance had been 2 inches per day, allowing an area of 100 square feet of roof and yard per head of population. The rapid increase of population in Woollahra and Waverley had rendered such an alteration necessary, and it had further been arranged to provide for this allowance for rainfall in Balmain, etc., though Mr. Clark's proposal had been to take the sewage-flow only. The allowance of 75 gallons per head per day, one-half running off in 6 hours, had been adhered to. The allowances for both sewage and rainfall varied considerably in different districts, as shown by the following Table compiled from the Paper. It would be seen from this Table that the rainfall-allowance had been calculated sometimes over the whole area, and sometimes over a certain area per head of population. It seemed much more accurate to treat the subject in the latter way, and it would have been better to retain the same allowance per head over the whole of the systems if possible, as variation in this respect led to considerable friction when the house-drainage was being designed in detail; for practically every owner wished to discharge the maximum allowance of rainfall into the sewers, though he might live in an area where the minimum was fixed. A uniform allowance of 2 inches per day, allowing 200 square feet per head would have made comparatively little difference, and might, with advantage, have been adopted throughout, except perhaps in the districts where chemical or other artificial treatment had been found necessary. The average rainfall in Sydney was about

Mr. Cook.

System.	District.	No. of Persons per Acre allowed for.	Sewage, how disposed of.	Sewage Allowance per Head per Day.	Rainfall Allowance per Day.	Remarks.
Northern	City	47	Gravitation to ocean	Galls. 75	½ inch over whole area	Surface steep.
	Suburbs	45 to 42	Ditto	75	2 inches over 100 square feet per head	Ditto
	North Waverley	30	Ditto	75	Ditto	Ditto
	Rush-cutter's Bay	25	Pumped to gravitation sewer	75	Ditto	Sloping to harbour.
	Pyrmont area	41	Ditto	75	Ditto	Chiefly wide valleys divided by spurs.
	Double Bay	30	Raised by Shone ejectors to gravitation sewer	50	Ditto	Low and flat; subsoil highly water-charged.
Southern	General	47	Gravitation to sewage-farm	75	40 per cent. of 3 inches over whole area	Surface flat.
Western	..	35	Ditto	75	2 inches over 200 square feet per head	Surface undulating.
	Marrick-ville	35	Portion pumped to gravitation sewer to farm	75	Ditto	Flat central low basin surrounded by fairly steep slopes.
Randwick	..	30	Gravitation to ocean	75	Ditto	High ground near ocean, flat and sandy inland.
North Sydney	North Sydney	35	Gravitation to area for precipitation and filtration	50	½ inch over whole area	Steep slopes. Good run-off for surface water.
	South Mosman	35	Ditto	50	⅜ inch over whole area	Ditto.
	North Mosman and South Willoughby	35	Ditto	50	¼ inch over whole area	Ditto.
M anly	..	..	Gravitation to ocean	50	1½ inch over 200 square feet per head	Chiefly flat and sandy.
Rookwood Asylum	..	..	Covered septic tanks and filters	50	..	..
Willoughby and Chatswood	..	31	Gravitation to septic tanks and bacterial filters	50	Nil	Good fall for surface-water into creek.

Mr. Cook. 50 inches per year, thunderstorms being rather frequent for about 4 months in the year. Mr. Clark stated in his report that rainfall exceeding 2 inches in 24 hours had occurred seventy-three times in 18 years. As the Author pointed out, heavier downpours were occasionally recorded, and could not be provided for in the foul-water sewers. To get rid of the excess, storm-water overflows had been provided, not only in the main outfalls but also in reticulation-sewers where storm-water ducts were available. It had been confidently expected that, when the Prospect water-scheme had afforded a liberal supply to the whole city and suburbs, and when the sewerage-scheme had been carried out, the consumption of water, instead of being about 27 gallons per head per day, would be 75 gallons. The following Table showed that

WATER SUPPLIED AND POPULATION SERVED BY SEWERS: SYDNEY, N.S.W.

Year.	Estimated Population supplied with Water.	Average Daily Supply per Head.	Estimated Population served by Sewers.
		Gallons.	
1890	343,204	24·70	109,272
1891	365,246	26·11	129,043
1892	378,885	32·12	150,729
1893	390,182	32·12	173,097
1894	401,380	34·23	191,832
1895-96 (18 months)	408,282	40·76	213,417
1896-97	418,512	42·20	228,446
1897-98	434,810	42·00	257,125
1898-99	450,483	41·72	281,856
1899-00	478,000	41·62	340,300
1900-01	491,000	43·96	364,440

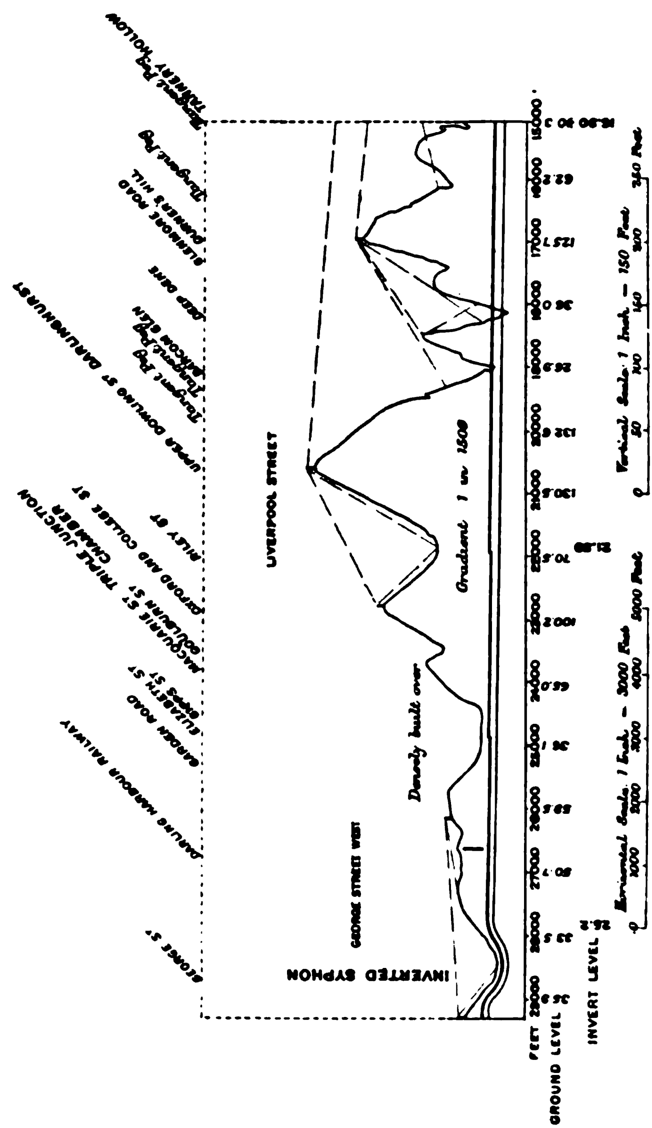
this expectation had not been realized, the average for the last 5 years being 42 gallons per day. It was quite certain that in a climate like that of Sydney, a very large portion of the water supplied was used for street- and garden-watering, and for other surface purposes during hot weather. A maximum allowance of 50 gallons reaching the sewers might therefore be taken as more than sufficient, while the 75 gallons originally allowed was certainly excessive. It would be seen that in designing the more recent schemes such as Double Bay, Manly, and Chatswood, 50 gallons only had been allowed for. Allowing for a population of 42 persons per acre, and allowing 50 gallons of sewage per head, one-half running off in 6 hours, with rainfall at the rate of 2 inches per day over an area of 200 square feet per head, the discharge would have been—sewage 0·47 cubic foot per minute

per acre; rainfall 0·97 cubic foot per minute per acre; total, 1·44 cubic foot per minute per acre, a result almost identical with the discharge allowed for in the aggregate in Table IV. in the Appendix, excluding Waverley North with a population of 30 per acre only. Mr. Cook.

In describing the works on the main outfall-sewer for the northern system, discharging into the ocean at Bondi, the Author might have dwelt at greater length on the magnitude of the operations. *Figs. 1* and *1a* showed a longitudinal section of the out-fall sewer from the cliffs at Bondi to the inverted siphon in George Street West, mentioned at p. 126, a distance of 5 miles 22 chains. The size of the sewer was 8 feet 6 inches by 7 feet 6 inches at the ocean end, and diminished in steps of 4 inches, till at 4 miles 24 chains at the triple junction shown in Fig. 5, Plate 3, the size was 6 feet 10 inches by 5 feet 10 inches, and at 5 miles 22 chains the size was 5 feet 1 inch by 4 feet 1 inch. It would be seen that the cliff rose perpendicularly from the ocean to a height of 156 feet; the surface then fell rapidly, till at 20 chains the water-charged drift sand was met with. To get rid of the water during the construction of the work, subducts had been laid, consisting of stoneware pipes, having open joints and a fall to the nearest shaft. Temporary connections from the inside of the sewer had also been put in at intervals to convey soakage water from inside to the subduct, so as to enable the cement rendering to be put on to springing-level (*Fig. 2*). These connections had afterwards been plugged and rendered over, as the work was otherwise completed. It had been thought that the use of a shield would be found necessary on this portion of the work, but finally the contractors had adopted a successful system of very heavy timbering, which had enabled them to carry out the work as shown. After leaving the wet sand the sewer was carried in rock tunnels for almost the whole length. At 81 chains the east portal of the Bellevue Hill Tunnel was reached. This tunnel was 6,173 feet in length and had been driven from two open faces and three shafts, known respectively as No. 4, No. 3 and No. 2, the depths from surface to invert being, No. 4, 79 feet; No. 3, 143 feet; No. 2, 238 feet, and the intermediate lengths as follows:—East portal to No. 4 shaft, 785 feet; No. 4 shaft to No. 3 shaft, 1,254 feet; No. 3 shaft to No. 2 shaft, 2,558 feet; No. 2 shaft to west portal, 1,576 feet. Bellevue Hill, which was a spur off the main ridge, was 320 feet high at the highest point on the line of the sewer. From the west portal of Bellevue Hill Tunnel a

Mr. Cook. short length of open cutting brought the sewer to Double Bay

Fig. 1.

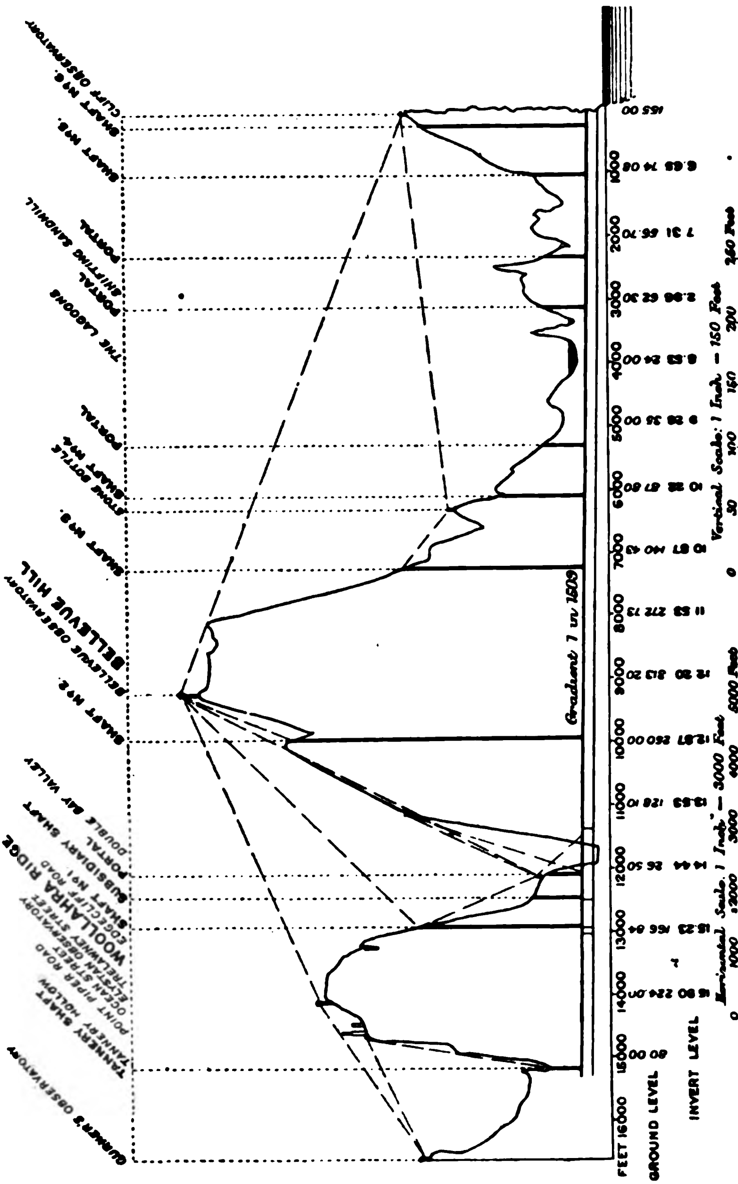


PART LONGITUDINAL SECTION OF NORTHERN OUTFALL SEWER, SHOWING METHOD OF ALIGNMENT OF TUNNEL.

Valley, across which it was carried on arches for a distance of

nearly 6 chains. Proceeding westward from Double Bay Valley Mr. Cook.

Fig. 1a.

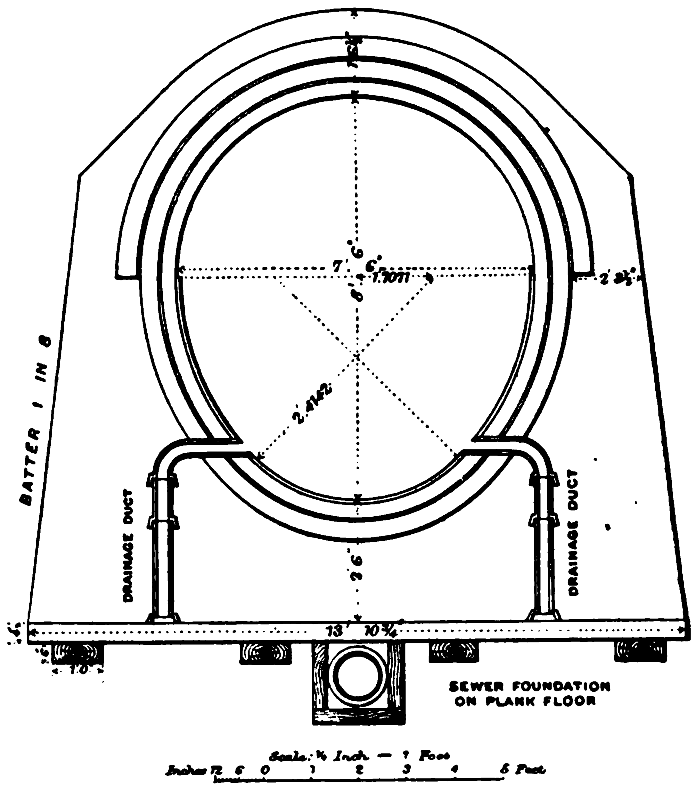


Part Longitudinal Section of Northern Outfall Sewer, showing Method of Alignment of Tunnel.

the Woollahra Ridge was next met with. The tunnel through this

Mr. Cook. ridge was 3,069 feet in length and had been driven from one open face on the east side and three shafts, two on the east and one on the west, named respectively, Subsidiary shaft, shaft No. 1 and Tannery shaft. The depths from surface to invert were 48 feet, 135 feet and 33 feet respectively, and the intermediate distances

Fig. 2.



NORTHERN OUTFALL SEWER, SYDNEY: TEMPORARY SYSTEM OF DRAINAGE DURING CONSTRUCTION.

were, East portal to Subsidiary shaft, 363 feet; Subsidiary shaft to shaft No. 1, 462 feet; shaft No. 1 to Tannery shaft, 2,244 feet. Between the cliff and a point near to the Tannery shaft, a distance of 2 miles 69 chains, the sewer was on a straight line. It then crossed the head of Rushcutter's Bay Valley on a 40-chain curve for a distance of nearly 16 chains. Still continuing, through shorter

and shallower tunnels, the sewer proceeded on a straight line to Barcom Glen, a distance of about 46 chains, crossing the Glen on a curve of 24 chains radius for a distance of about 7 chains. The sewer then passed through the hill at Darlinghurst in a straight tunnel about 46 chains long, driven from shafts 7 or 8 chains apart. The deepest shaft on this hill was 143 feet in depth, while the highest point of the surface was 167 feet above sea-level. At 4 miles 24 chains the junction-chamber shown in Fig. 5, Plate 3, was reached, where the large city branches entered, viz., Kent Street and Hyde Park, the sewer-invert being 90 feet below the surface. From this point onward the sewer was chiefly in tunnel at shallow depths till the inverted siphon was reached at a distance of 5 miles 22 chains from the ocean. The items of interest on the main line of sewer beyond this point, towards Balmain, were described in the Paper. With regard to the setting out of the tunnel, the following account, for which he was indebted to Mr. J. H. Cardew, Assoc. M. Inst. C.E., who had had sole control of the alignment and levels throughout the main-outfall works, might be of interest:—The line of the outfall-sewer was first run with a 5-inch theodolite in April, 1880, the ridges and principal points being marked with stones, having each an iron plug centred in it. On account of the rugged nature of the ground, and the many obstacles such as buildings, etc., great difficulty was experienced in laying out the line, and more particularly the curves. It was therefore considered desirable to obtain from Messrs. Troughton and Simms a special transit-instrument. The telescope had a focal length of 34 inches, the object-glass being 3 inches in diameter; and there were three eye-pieces of powers 30, 50, and 120. A special feature of the instrument was the provision of delicate slow-motion screws, by which the upper portion of the instrument was moved transversely on the bed-plate when setting up on a point. One complete revolution moved the plate $\frac{1}{100}$ inch only. Before the arrival of the instrument, work had already been begun in shafts and drives, but the alignment had been checked with an 8-inch theodolite, and the erection of observatories had been proceeded with on the principal ridges along the line. These observatories were hollow frustums of pyramids, built upon massive concrete foundations and well ventilated, so that the temperature inside should be the same as that outside. Each was covered with a galvanized-iron house, built on uprights around the stone column but not touching it. At each side of the house were doors opening on to the lines, with a platform outside for signalling purposes. On the top of the frustum was a square smooth Mr. Cook.

Mr. Cook. dressed stone, carrying a graduated brass scale, on which the centre line could be indicated. In the longitudinal section of the tunnel (*Figs. 1* and *1a*) the method of alignment was shown. Some work having already been set out with the 8-inch theodolite, it was decided to adopt as a base the line joining the Woollahra and Bellevue ridges, and to produce this line each way with the new transit on its arrival. The ranging was done both by night and by day; but observations made in the daytime were found to be unsatisfactory unless taken between daybreak and sunrise, owing to the disturbance of the atmosphere by the heat of the sun, or the smoke from houses and winding-engines at the shafts. The vertical plane of the tunnel being thus established on the surface, intermediate points were fixed on each side of the shaft, and stone columns were built to enable accurate observations to be made with the transit. The surface of these columns was about 2 feet higher than the platform over the shaft, and about 30 feet apart. The plumb-lines down the shafts consisted of steel wire 0·017 inch in diameter, suspending a 16-lb. bob. These were ranged between columns with the 8-inch theodolite. At the bottom of the shaft a scale was fixed in a block of hardwood, securely let into the rock over the arch of the drive, so that when the wire came down the shaft it should just touch the edge. An observer at the bottom of the shaft read off the position of the wire on the scale. The shafts were 12 feet along the line, and the base line obtained in the shafts was 11·7 feet. When transferring the line into the drives, short plumb-bobs were suspended at the mean readings over the scales on each side of the shaft. In this way very satisfactory results were attained, as the following examples of meetings of drives showed: shaft No. 1 to Double Bay portal, discrepancy $\frac{1}{4}$ inch; shaft No. 2 to Double Bay portal, discrepancy $\frac{11}{20}$ inch; shaft No. 2 to shaft No. 3, discrepancy $\frac{1}{8}$ inch: this was the longest drive, viz., 2,558 feet. The meeting on the 40-chain curve across Rushcutter's Bay showed a discrepancy of $\frac{3}{4}$ inch. Most of the short drives of 600 feet and 1,000 feet met exactly. With reference to the North Sydney outfall-works at Willoughby Bay, Mr. J. M. Smail, M. Inst. C.E., Engineer-in-Chief of the Board of Water-Supply and Sewerage, in a recent report[1] had said—

"With precipitation systems either mechanical or chemical, in other parts of the world, the disposal of the sludge has been a difficult matter, and the Willoughby works is no exception . . . With the North Sydney works . . . favour-

[1] "Twelfth Report of the Metropolitan Board of Water-Supply and Sewerage," p. 85. Sydney, 1901.

able conditions do not obtain, and unless the sludge is disposed of by digging in on the filter bed it must be destroyed by fire. To convert the filtering area into a sludge pit would defeat one of the objects of the system, and this method could only be adopted in a small way to make up depressions or banking up the distributers. A quantity has been disposed of in this manner without causing a nuisance or deteriorating the bed as a filter. Mr. Cook.

"After some months of working it was found that the cost of lime for precipitation and forming sludge-cake, together with the cost of fuel for burning the latter, was so great that experiments were tried in mixing some combustible material with the sludge. Sawdust and coal-dust were tried, but in neither case was the result conclusive as to economy, and mixing lime with the sludge had to be reverted to.

"If lime precipitation has to be continued, some other method of mixing lime and sludge will have to be adopted to obtain satisfactory results. The quantity of coal used for burning the sludge-cake is 9 cwt. to 2½ tons of "cake" during an eight-hour shift, or 18 per cent. . . . The cost of working the outfall works, including wages, lime, coal, &c., from 1st August, 1899, to 30th June, 1900, was £1,334 2*s.* 5*d.*; of this amount, wages absorbs £661 10*s.* 3*d.*, and coal-lime £613 0*s.* 6*d.*

"In view of the heavy cost of working the system it is desirable, in the interests of the ratepayers that some more economical method of disposal should be tried, and with this object the Board approved of one of the precipitation tanks being converted into a bacteria bed on the Scott-Moncrieff principle. If this mode of treatment is successful—and there is every ground for thinking it will—an important question in connection with these works will be solved."

The cost of lime delivered on the works was £2 per ton, and coal cost 22*s.* 6*d.* per ton delivered at wharf. Since 1888 the death-rate of the city had shown a downward tendency on the whole, though it was marked by considerable fluctuations, the population meanwhile decreasing from 120,000 to slightly less than 100,000. On the other hand, the suburban death-rate had decreased from slightly over 19 per 1,000 in 1888 to about 11·5 per 1,000 in 1900, with a minimum of 9·87 in 1897; while the population had increased from 220,000 to 330,000. Exclusive of hospitals the death-rate for the suburbs in 1897 was 7·78. The city had been sewered previous to 1888, though the sewage had merely been discharged into the harbour, but in the suburbs practically nothing had been done, so that all natural watercourses had been simply open rough foul sewer-channels.

Mr. E. Cuthbert remarked that Mr. Davis's Paper seemed to be an excellent one, but he could not help thinking that it was a pity the Author had not touched on the all-important part of a sewerage scheme, viz., house-connections, and had not described briefly how they were laid, the construction of the internal fittings as regarded material and design, the size of soil- and waste-pipes, etc. He believed he was right in saying that in Sydney the disconnecting-trap was placed outside private property, that it did Mr. Cuthbert.

Mr. Cuthbert. duty as a fresh-air induct, and was ventilated at the head of the connection by an upcast shaft and cowl. That plan had been tried in Christchurch, N.Z., for a short time after the sewers were available for connections, but had not appeared to answer. The district was so flat that in many cases the fall in the connection-pipe was necessarily very slight (sometimes 1 in 200 for 4-inch pipes). There was consequently insufficient head to keep the trap clear when so placed, as of course no drop could be given, and it became choked. Comparatively few houses had been connected when he had taken charge of the works in 1882; but since that time he had kept the disconnecting-traps for all purposes (water-closets included) at the head of the connections. Where an internal water-closet was provided, or where the length of the connection exceeded 150 feet, a main ventilator 3 inches to 4 inches in diameter, with exhaust-cowl attached, was placed, and this drew directly from the sewer. He would much prefer a main ventilating-shaft at every connection; but in poor localities the cost would be likely to prevent the sewers being taken advantage of to the same extent as at present. He was aware that this system was condemned by some authorities and upheld by others; but he would much like to see the question discussed by members of the Institution, as it was one of great importance. With regard to the ventilation of sewers, he did not think anything could be more effective than frequent openings on the surface of the streets. It might be said that it was not right to insist on ventilation of the public sewers by private individuals; but there was really no hardship attached to this method, as they would have to provide exactly similar air-shafts to ventilate their system from the disconnecting-trap, and these ventilators could not be more objectionable from any point of view than the exhaust-shafts mentioned by the Author, which, he presumed, were carried up the house-walls. The openings in the streets in Christchurch were attached to each man-hole, and were so constructed that no road-detritus could find its way into the sewers. Their average distance apart was about 6 chains. Complaints of bad smells from them were now very rare, as they really did duty as fresh-air inducts, the private ventilators before mentioned acting as exhausters. He could not help thinking that this mode of ventilation was more effective than that described by the Author. It would also be interesting if the Author would give particulars as to the flattest gradients in pipe-sewers of various sizes. About sixteen years ago he had laid a 9-inch pipe, 45 chains in length, to connect the Addington railway workshops and the sewer, with a gradient of 1 in 525. He had warned the Government authorities, who had

defrayed the cost, that he would not guarantee its action. However, it had been that or nothing, and the pipe had not given the slightest trouble since the day it was laid. Gradients of 1 in 450 for 9-inch pipes and 1 in 600 for 12-inch pipes were common in Christchurch, and worked well. He should mention that the system was strictly a separate one, and that the pipes were flushed regularly. The sludge was not ploughed in on the farm there. It was of poor manurial value, and he thought it was apt to choke the pores of the soil. Mr. Cuthbert.

Mr. W. FAIRLEY considered that the Paper on the sewerage systems of Sydney was of great value. Covering so much ground, it naturally omitted many details of interest, giving only the broad lines and principles followed in designing the different systems described. He thought, however, its value as a Paper for reference would be materially enhanced if some further Tables were added giving a few details of the cost of pumping, and of sewage-purification. In the matter of pumping, there were described stations where steam-engines and plunger-pumps alone were used and others equipped with centrifugal pumps, an area worked on the sectional system by plunger-pumps driven by electric motors and an area worked on the sectional system by Shone ejectors; all of these in the same district and, he supposed, under one authority; giving an opportunity seldom met with for an analysis of the annual expense of maintenance of the different systems. The system adopted of pumping on the sectional system by electric motors was, he believed, novel, or at least had not been formerly tried on so large a scale; but it was one which offered great facilities for efficient and economical working, and also in construction, as compared with the hydraulic or pneumatic systems in present use. It would be of interest to know the reason for adopting plunger-pumps which must necessarily be geared down from the motors. A high-speed motor and a low-speed reciprocating pump did not appear to be a desirable combination, and certainly required a heavier capital expenditure, both for the sub-stations and pumps, than motors coupled direct to centrifugal pumps. About two years ago, in preparing a scheme of drainage for an area which had to be treated on the sectional system, owing to the very flat nature of the district, he had proposed, in place of the pneumatic or Shone system, to generate electricity at the outfall-works, and to have centrifugal pumps and electric motors coupled on the same spindle at the sub-stations, the whole being controlled from the outfall. This combination of pump and motor lent itself to more economical and cheaper forms of sub-station and Mr. Fairley.

Mr. Fairley. plant than the plunger-pumps mentioned. Possibly the Author could give some further details as to the expenditure on repairs, renewal of valves, etc., and also as to the precautions taken to keep the valves clear and the pumps charged. No details were given as to rainfall, and no particulars as to how far the separation of rainfall and sewage was effected. Much depended upon this in determining the capacity of the sewers, which in the Paper varied between 75 gallons of sewage per head per day and 1 inch to 2 inches of rainfall, and 40 gallons of sewage per head per day and 1½ inch of rainfall; all these districts being, he presumed, under practically the same climatic conditions in regard to rainfall, etc. The cost of the works per head of the population, as compared with home practice, was rather high; at the same time the rate charged of 1*s*. in the pound was certainly not excessive. With regard to the purification of the sewage, it would appear that no very high standard of purity could be necessary, the effluent in every case being discharged into tidal water. Possibly the Author could give the cost, including interest on capital, per million gallons treated, as the different systems he had adopted were fairly representative of present practice. With regard to the double outfall for discharge into the sea at Bondi, on several works with sea outfalls the late Mr. Sutter, M. Inst. C.E., had had T-pieces fixed on the discharge ends, and this quite prevented shock to the sewers from waves running up the pipes and causing the sewage to surge back. These outfalls, however, were much smaller than that described by the Author, and it was quite possible that the wave-action at the point mentioned in the Paper would not admit of such a simple expedient.

With regard to the Paper on the treatment of trades waste, he thought it was generally admitted that where a discharge from a manufactory was polluted with organic matter, treatment on bacterial lines should prove successful. At the same time, his experience was that, where no direct recovery of any by-product was part of a process, so that some slight pecuniary gain might be reaped, after the works had been constructed little or no interest was taken in their working. They were left in charge of labourers of the most ordinary intelligence, with, of course, the usual results; and he thought there could be no doubt that want of success in the treatment of both trades waste and sewage was very often due to unskilful labour and management. The Author being in an exceptional position for obtaining information on this subject, the experiments mentioned and the conclusions drawn must form a valuable contribution to the Proceedings.

Mr. T. Griffiths considered that Mr. Davis was to be complimented on his full and complete description of the sewerage systems of Sydney. Having been engaged on the works under the Metropolitan Board of Water-Supply and Sewerage since its formation in 1890, he could give some information as to the works described by the Author since they had been in use. The works generally had been very substantially constructed, and no expenditure had been incurred by the Board for any repairs to them. The sewers were designed to be self-cleansing, and were graded with that object. He was pleased to state that this object had been practically attained, and when the scheme was completed he had no doubt as to the result. The principal portion of the silt removed might be attributed to the points of interception with old combined sewers, and flushing removed all but the siliceous and harder material. The local drift sand was very difficult to deal with, not only in the sewers, but also in the open storm-water channels; in some of the latter, provision was made for dealing with the dry-weather flow by constructing a small channel along the middle of the invert, the object being to increase the depth of flow during the period of dry-weather flow, and thus render the sewer self-cleansing. This object, however, had not been attained, the sand settling and silting up the central channel, which had to be cleaned out periodically. With regard to the ventilation of the sewers, in addition to the various brick shafts and galvanized-iron shafts erected by the Board, advantage had been taken of all chimney shafts of factories and breweries in the vicinity of main sewers, the proprietors of which had readily permitted the Board to connect therewith. The Table at pp. 224 and 225, extracted from the Twelfth Report of the Water-Supply and Sewerage Board, was a list of the special shafts referred to. It might be pointed out that prior to the ventilation of the sewers, the men had been unable to work below for any length of time, the air being surcharged with moisture. Since the present system of ventilation had been introduced, the men worked in the sewers with every comfort and with no ill effect on their general health. It had also been noted that since the sewers had been ventilated, the interior surfaces had all become dry where they had previously been wet. With reference to the water-spray system of ventilation in combination with the system of automatic flushing-tanks, it might be mentioned that the special nozzles, which gave the water a rotatory motion on leaving the orifice, used 60 gallons of water per hour; the effect, at a pressure of 60 lbs. per square inch, was the removal of 60,000 cubic feet of air in that time. In reference to the subsoil Mr. Griffiths.

Mr. Griffiths.

SEWERAGE SYSTEMS OF SYDNEY, N.S.W. SPECIAL SHAFTS, WATER-SPRAYS, STACKS, &c., 1899 AND 1900.

Locality.	Time of Test. H. M.	Lineal Feet during Test.	Lineal Feet per Hour.	Cubic Feet per Hour.	Miles per Hour.	Pressure per Square Foot. Lbs.
Exhaust, 9 inches in diameter, Crown Street, new stack	21 0	1,304,400	62,114	27,442	11·76	0·6914
„ 6 „ „ „ McCorquodale's Mills, stack	17 30	1,895,900	108,337	21,272	20·51	2·1033
Induct, 6 inches in diameter, Edgecliff Road, spray	16 0	652,200	40,762	8,004	7·72	0·2979
Exhaust, 6 inches in diameter, Cameron's Factory, stack	2 30	77,600	31,040	6,095	5·87	0·1722
„ 6 „ „ „ Tooth's Brewery, stack	5 0	696,000	139,200	61,498	26·36	3·4742
Induct, 18 inches in diameter, Pitt Street, spray	73 30	2,140,000	29,115	51,449	5·51	0·1518
„ „ „ „ „ Glen Street, spray	72 30	2,800,800	38,631	68,265	7·31	0·2672
„ „ „ „ „ Campbell Street, spray	73 0	3,571,160	48,920	86,462	9·26	0 4287
„ „ „ „ „ Dumbarton Street, spray	23 30	1,138,700	48,455	85,624	9·17	0·4204
Exhaust, 36 inches in diameter, Bellevue Hill	17 30	732,000	41,828	295,665	7·92	0·3136
Induct, 18 inches in diameter, Illawarra Road, spray	24 0	1,279,700	53,320	94,222	10·09	0·5090
Exhaust, 9 inches in diameter, Lassetter's, stack	1 0	14,400	14,400	6,362	2·72	0·0369
„ 6 „ „ „ Taylor Bros., stack	94 0	5,571,100	59,267	11,637	11·23	0·6305
Induct, 18 inches in diameter, Burren Street, spray	48 30	2,474,200	51,014	90,146	9·65	0·4656
Exhaust, 6 inches in diameter, New York and Brooklyn, stack	1 30	91,200	60,800	11,938	11·51	0·6624
„ 10 inches × 9 inches, Hordern's, stack	0 45	28,200	37,600	23,500	7·12	0·2534
„ „ „ „ „	0 45	10,800	14,400	9,000	2·72	0·0369
„ 6 inches in diameter, Boyce's Jam Factory, stack	112 0	3,646,900	32,561	6,393	6·16	0·1897
„ 26 inches × 26 inches, obelisk	21 0	713,500	33,976	159,687	6·48	0·2067

Mr. Griffiths.

SEWERAGE SYSTEMS OF SYDNEY, N.S.W. SPECIAL SHAFTS, WATER-SPRAYS, STACKS, &c., 1899 AND 1900—*continued*.

Locality.	Time of Test.	Lineal Feet during Test.	Lineal Feet per Hour.	Cubic Feet per Hour.	Miles per Hour.	Pressure per Square Foot.
	H. M					Lb.
Induct, 18 inches in diameter, Bourke Street, spray	1 0	16,600	16,600	29,334	3·14	0·0193
,, 9 ,, ,, ,, Darling Point, spray	16 0	604,000	37,750	16,678	7·15	0·2556
Exhaust, 63 inches in diameter, The Warren	1 0	47,600	47,600	1,030,421	9·01	0·4059
Induct, 12 inches in diameter, Erskine Street, spray	1 0	22,800	22,800	17,907	4·31	0·0928
,, 18 ,, ,, ,, Kent Street, spray	1 0	8,400	8,400	14,844	1·59	0·0126
,, ,, ,, ,, ,, Macquarie Street, spray	1 0	9,600	9,600	16,964	1·81	0·0163
,, ,, ,, ,, ,, Loftus Street, spray	1 0	35,400	35,400	62,555	6·70	0·2244
,, ,, ,, ,, ,, Harrington Street, spray	1 0	16,200	16,200	28,627	3·06	0·0468
Exhaust, 18 inches in diameter, Liverpool and Elizabeth Streets, spray	3 0	100,500	33,500	59,198	6·34	0·2009
Exhaust, 18 inches in diameter, St. James' Road, spray	1 0	34,200	34,200	60,435	6·47	0·2093
,, ,, ,, ,, ,, Bathurst and Elizabeth Streets, spray	1 0	34,400	34,400	60,788	6·51	0·2119
,, ,, ,, ,, ,, Castlereagh Street, spray	1 0	20,800	20,800	36,756	3·93	0·0772
Induct, 25 inches in diameter, Busby Bore, spray	1 0	94,800	94,800	323,154	17·95	1·6110
Exhaust, 36 inches in diameter, St. Leonards	48 0	1,233,100	25,690	181,592	4·86	0·1180
Induct, 18 inches in diameter, Purves Lane, spray	41 0	1,148,700	28,017	49,509	5·30	0·1404
Exhaust, 18 inches in diameter, Kerosene Works, stack	24 0	1,089,500	45,400	80,226	8·59	0·3689
,, 36 ,, ,, ,, Victoria Park	20 0	570,000	28,500	201,455	5·39	0·1452
,, 6 ,, ,, ,, Cornwell's Brewery, stack	1 0	21,900	21,900	4,300	4·14	0·0856

Mr. Griffiths. drainage of sewage-farms at Rockdale and Botany, it might be pointed out that considerable difficulty had been experienced in making a joint which would admit water and at the same time exclude the fine drift sand. Experiments extending over a long period had been conducted with various materials, with the result that Cochin fibre mats, sewn to agricultural pipes spaced 1 inch apart and surrounded with coarser sand, had been adopted. This system had been in use for about two years with the greatest success, as no sand passed into the pipes. It had been found necessary to keep a special watch over the inlet-gratings of the siphons at George Street West, and at Illawarra Road, Marrickville, as they were liable to become choked and thus to retard flow. At Marrickville, the gratings had been altered so as to admit of the passage of larger material, as it had been found that during rain-storms the gratings became choked and the water backed up and flooded the lower levels. Since this alteration matters had improved. Owing to the difficulty of dealing with storm-water at the sewage-farms, additional overflows had been provided at Woolli and Muddy Creeks. The storm-water discharging into them during rain-storms bore a ratio of 35 : 1 to the sewage, and therefore was purer than the water in the creeks.

Mr. Hickson. Mr. R. R. P. Hickson remarked that his first connection with the sewerage scheme for Sydney and suburbs had taken place in the year 1889, when he had been appointed successor to the late Mr. W. C. Bennett, M. Inst. C.E., as Engineer-in-Chief for Roads, Bridges and Sewerage. At that time the main Bondi sewer from the Glebe to the outfall, and the main southern scheme from Paddington to the Botany sewage-farm, had been completed; there remained, however, all the branch sewers to be completed, and the extension of the Bondi sewer from Glebe to Balmain. Previous to his taking charge of the works, Parliament had voted a sum of £1,817,896 to carry out what was known locally as the "Western Suburbs" sewerage scheme, which was described in the Paper. During the progress of this portion of the work he had come to the conclusion that while this system of construction was thoroughly efficacious, and at the same time had a very good artistic effect, the cost was excessive; and he had instructed the principal assistant engineer to prepare, on a more economical basis, a design for that portion of the sewer which had to cross the Arncliffe flats. The design eventually decided upon had consisted of brick arching with concrete ducts, instead of the iron ducts over the Cook's River and Wolli Creek; the cost of this had been considerably less, but, at the same time, owing to the contraction

and expansion of such a large body of concrete, great care had had to be exercised in order to make the structure water-tight. About this time the question of extending the Bondi sewer from its terminus at the Glebe to Balmain had been under consideration; and, as two valleys had to be crossed at a considerable height, the question of the most suitable design had required a good deal of consideration; plans had been prepared on the most economical basis then known in the department, and tenders had been invited. One of the tenderers, however, had sent in a design of his own on the Monier system at a cost less than the lowest tender received on the departmental design. Mr. Hickson had given a good deal of consideration to this Monier system of construction, and had been very anxious to give it a trial in New South Wales. Some small structures, previously constructed, had appeared to answer all requirements; and, after considerable deliberation, the Monier design had been accepted on very stringent terms, the main feature of which was that, if, at any time during a period of three years after completion, the design in any way failed or was not accepted by him, or by whoever happened to succeed him, the contractors were to take the whole structure down and rebuild it on the departmental design without any extra payment. It would, he thought, be admitted that these terms were not only very stringent, but in every way met the circumstances of the case, as far as the financial interests of the Colony were concerned, in the event of failure. The contractors, being satisfied as to the value of their design, had accepted these terms and the work had been carried out; and although it had received a very severe test, having had for some months to stand the great heat of summer and the cold of winter without any liquid in the pipe, the construction had proved to be all that had been expected of it, not a single crack appearing in the two structures, the lengths of which were, respectively, 825 feet and 823 feet. Subsequently to his relinquishing the position to take that of permanent head of the Department, Mr. Davis, who had been his right-hand man, and to whom he was greatly indebted for the assistance he had rendered, had been appointed Engineer-in-Chief for Sewerage, and the various extensions which he had described at North Sydney, Willoughby, and other places, had been carried out by him. Without having an intimate knowledge of the configuration of Sydney and suburbs it was hard for any one to realize the great difficulty that presented itself in the designing of a sewerage scheme, no one scheme being able to deal with the whole area; but he thought that, when the whole was completed, Sydney with its suburbs would be as well sewered

Mr. Hickson.

Mr. Hickson. as any city with which he was acquainted. Much had been said, from time to time, as to the advantages of the various ways of disposing of sewage; he thought it would be admitted that, wherever possible, it was better to get rid of the sewage into the ocean; but as there were very few places where this could be done without seriously affecting the foreshores, some artificial means had to be used. In his opinion the choice of artificial means rested between precipitation and filtration on a sewage-farm and the septic tank with bacteria-beds. The Botany sewage-farm was an ideal place for precipitation and filtration; it was an enormous sand-bed, in fact far larger than would ever be required, and the effluent from the filter-beds in this area proved beyond all question the efficiency of the system. There were few places where such an area could be found, and generally the next best system, that was to say, the septic tank and bacteria-beds, had to be adopted. The principle of the septic tank was so well known that it was unnecessary to enlarge upon it; he was satisfied, however, that it was a complete success, and he would have no hesitation in using it where there was no sea-outlet, and where a sandy area like the Botany sewage-farm was not available. The sewerage system of the city and suburbs had caused the mortality of the population per 10,000 persons to be reduced from 189·2 to 130·0, more especially under the headings of typhoid and diphtheria. The ventilation of the main sewers was well supplemented by the excellent ventilation of the reticulation-sewers and house-connections.

Colonel Jones. Colonel ALFRED S. JONES, V.C., observed that he was disappointed to find Mr. Naylor's enthusiasm for bacterial action diverting his attention from the search for the application of chemical and gravitation forces by manufacturers to arrest, and in some cases to recover, useful products from the stream of foul waste, before it joined a town's sewerage system. A great deal had been done and remained to be done in this direction at the factory, where the exact chemical composition of the waste could be known and was always of a much simpler character than complex mixtures like sewage. If sewage had to be imported for the sake of the bacteria it held, in order to work upon the manufacturing waste as proposed in Mr. Naylor's Paper, why not let all go through the sewers to be bacterially treated at the common outfall? It was only in rare instances of excessive proportion of some trades waste in a sewage that bacterial action was delayed or interfered with in proper sewage-disposal works; but any preliminary reduction of that proportion could best be achieved at the sources of trades waste, by

chemical, magnetic, gravitation, or other means; and it appeared to him that factory-owners should not be discouraged, by being led into expenditure on bacteria-beds, from the simple work which alone ought to be expected from them. Colonel Jones.

Mr. R. T. McKay, of Sydney, remarked that Mr. Davis had dealt in a comprehensive and exhaustive manner with his subject from the date when the first primitive sewers were laid in the City of Sydney to the present time. The preparation of such an extensive Paper certainly required a considerable amount of time and labour, and the Author was to be congratulated on bringing under notice the various systems of sewerage-construction and sewage-disposal obtaining in Sydney and its suburbs. The Tank Stream, upon which Governor Phillip had established his settlement in 1788, and which for many years had been the source of water-supply for the township, had become, as the Author stated, gradually contaminated as settlement increased. Instead of being a stream of pure fresh water it had eventually become the main drain of the town. New South Wales having been a Crown Colony and without responsible Government until the year 1856, and all available money having been required for the development of the country, there had been many difficulties in the way of the early settlers in dealing with the question of improved sanitation; in fact, between 1788 and 1853 nothing had been done. In the latter year the appointment of three Commissioners had led to the establishment of the old and very imperfect system of sewerage within the city. The Tank Stream and other natural watercourses had been constructed principally of stone with uneven inverts, and had gradually become the receptacles of all kinds of filth. No system of ventilation had been designed. In the connections to these sewers clay had been the only jointing material used, and in many cases this had been omitted. In 1875, when, as the Author mentioned, no less than seven thousand closets were being discharged into these old sewers, the general mortality of the community had been increasing to such an alarming extent that it had been time that the Government of the day thought fit to appoint a body of experts to report on the sanitary arrangements of the city. The outcome of that report had been a recommendation that a comprehensive system of sewerage should be adopted. Parliament had subsequently agreed to the proposals, the result being that Sydney now possessed perhaps one of the best and most complete systems of sewerage in the world. The configuration of the city, with its immense coast-line of 170 miles, together with the facts that much Mr. McKay.

Mr. McKay. of the work was in tunnel through hard rock, and that in other places drift sand of great depth had been met with, had added considerably to the cost of the scheme. In carrying out the early contracts at the initiation of the work, material had been expensive, labour difficult to obtain, and contractors inexperienced in sewer-construction. He would like to have seen a comparison by the Author of the prices of labour and material prevailing then and now. The main Bondi sewer of the Northern system had been the first work put in hand by the Public Works Department. This was of considerable magnitude, and the Author's description of the ocean outfall at Ben Buckler Head showed that it had been a difficult piece of construction. The fact that it had stood the test for 17 years, on a headland exposed to an angry ocean, proved that much care had been exercised in the design and execution of the work. In the Bondi flats great trouble had been experienced in the tunnel and open cuttings, which were in wet drift sand, and timbering and draining had involved considerable expense. No timber had been removed from the tunnels, and in the open cuttings the lower sets of timber had been covered up. About three years ago he had had charge, as Resident Engineer, of the construction of the Bondi intercepting sewerage scheme, and in carrying out the work it had been necessary to effect a junction with the main sewer in the Bondi flat referred to by the Author, where the open trench was about 30 feet deep. Although the timber had been in the ground for a period of 14 years, he had found it almost as sound as the day it was placed there. The sewer-lining of concrete and brickwork had also been in a perfectly sound condition. The Monier aqueducts crossing the Johnstone's and White's Creek valleys had a particularly graceful appearance, and, being on the main thoroughfare from Sydney to Balmain, were frequently observed and much admired. The Main Northern system, which drained an area of about 8,000 acres, was now almost completed. All the main sewers were finished, and also the greater portion of the reticulation. The low-level sewers on this area were well in hand, and he had had charge of the construction of three of the pumping-stations, which were now complete and ready for the installation of the machinery. The Southern system, draining a populous area of 1,306 acres, had been completed for some years, and had converted a most insanitary portion of the suburbs of Sydney into a desirable residential area, with an extremely low death-rate. At the outfall-works of this system, after the sewage had been screened and precipitated, the effluent passed under Cook's River

by means of an inverted siphon of cast-iron pipes to the Botany sewage-farm. It was to be regretted that the siphon had not been laid at greater depth under the river-bed, as it was now causing some trouble to the authorities, who were considering the question of deepening the channel with a view to make the river navigable for larger vessels. With regard to the sewage-farm, much had been done in the way of raising crops, and excellent beds of maize, sorghum, and turnips were now grown. The largest portion of the sewerage of Sydney and its suburbs was the Western Suburbs sewerage scheme, which, when completed, would drain the large area of 13,000 acres. The main carrier of this system discharged on the Rockdale end of the Botany sewage-farm, where a large area had been prepared for filtering the effluent after it had been screened at the outlet. It seemed as though Nature had intended this area for the purpose to which it had been devoted. The land, which was practically a barren waste, was composed of drift sand, and, although worthless for commercial purposes, was admirably suited for a sewage-farm. Under his immediate supervision, and by the Author's directions, a sum of £30,000 had been spent in preparing and levelling the land into different beds, each having an area of about 20 acres. In the banks dividing them, subsidiary drains had been constructed with sluice-gates, and a penstock-chamber at the junction of the carrier, so that the sewage could be directed on to any bed. Various experiments had been made to determine the best method of under-draining the beds, including the laying of perforated and porous pipes surrounded by various material to keep the sand out, while allowing filtration. The greatest success had, however, been obtained by using ordinary earthenware pipes laid with open joints very carefully surrounded by strips of closely woven jute. He had recently seen a piece of this matting which had been in the beds for two years, and was still serving its purpose efficiently, with every prospect of acting satisfactorily for many more years. It had been thought that it would decay in a few years, but the experiments had proved so successful that this jointing-material was now used entirely in under-draining the Western Suburbs filtration-area. The triplicate circular outfall-sewer from Premier Street to the sewage-farm, which had been described by the Author (p. 135), was in itself a work of great magnitude, the cost approaching £250,000, and provided for all possible expansion of population. He was inclined to think that less costly structures might have been designed for aqueducts at Cook's River and Walli Creek, and a saving might have been effected by reducing the Mr. McKay.

Mr. McKay. bulk of material in the arches and abutments. On the eastern intercepting-sewer it was perhaps open to question whether the siphon (which was not always the most desirable expedient in sewer-construction) on Illawarra Road might not have been avoided with advantage. A satisfactory deviation in higher ground to the west could have been obtained with only a very slight loss of gradient, while at the same time a suitable position for an overflow would have been provided. Generally, the Western Suburbs sewerage system, which was now being completely reticulated, had entirely changed these suburbs from a residential point of view, and served a vast and rapidly increasing population. The Marrickville low-level area, comprising a large basin of low ground with only a narrow outlet to Cook's River, had presented considerable difficulties, complicated by the want of natural facility for an outlet for the storm-water from the adjacent higher lands. The catchment-area of 1,700 acres discharged with great rapidity on the low-level valley of not more than 100 acres, causing much distress to the poorer residents, who had bought and built on this area in times of land booms. As Resident Engineer he had experienced considerable difficulties in the execution of this scheme. The trenches had had an average depth of 13 feet, and had had to be securely timbered throughout. The septic tanks and filter-beds now constructed and in use at Rookwood and Chatswood, had worked most satisfactorily, and without doubt this method would, for economical reasons, be adopted in most of the inland towns of the State, especially as deep-water outlets were not available. At the present time he was engaged on the installation of a bacterial system for the towns of Liverpool and Narrandera, the former being 22 miles from Sydney, with a population of 2,500, and the latter in the interior of the State, 350 miles from Sydney, with a population of 3,500. There was little to add to the Author's description of the low-level systems, except that it was to be regretted from a sanitary point of view that the low levels in the city proper had not been dealt with in conjunction with the high-level Northern system. Had this been done in the early eighties, even at the cost of separate local pumping-centres, the effect of the recent plague and other visitations would have been considerably diminished. On the other hand, the mechanical advantage of a uniform and comprehensive scheme worked from one controlling centre was apparent. A glance at the Tables in the Appendix in regard to sewered and unsewered localities of the suburbs of Sydney would show the gradual decrease in

the rates of mortality during the extension of the sewerage scheme between 1884 and the present time. He was satisfied that a still greater reduction would be made when the low-level areas had been connected with the Northern and Western systems. Mr. McKay.

Mr. FRANK E. PRIEST remarked that he noticed jumping-weirs had been used on the Sydney sewerage works, and as this device seemed to have become obsolete at home, he wondered what special reasons there were in the present instance for their adoption. Ingenious as the idea appeared at first sight, jumping-weirs were only useful where it was desired to send the whole volume over the weir in times of storm. Where purification-works were intended to be relieved of all duty during storms, they had an advantage; but in the present instance no such cause seemed to authorize their adoption. Considerable variation in the quantity of storm-water carried with the sewage appeared throughout Mr. Davis's Paper. The figures given in describing this provision did not show clearly the relative dilution in the several parts of the system. The Author had provided for large and varying daily consumption of water per head, in some cases as much as 75 gallons being taken, and in others 40 gallons; and the quantity of rainfall had been based upon certain quantities of rainfall varying between ½ inch and 2 inches per head of the population per day, collected on varying areas. This seemed to be a cumbrous method of providing for the necessary dilution of the sewage. The actual quantity of water supplied to the population, while it might affect the quantity of sewage produced, would also affect the strength of that sewage; and therefore it would seem better to assume a number of gallons of sewage per head, which would depend upon the neighbourhood rather than the water-supply, and would be influenced by the uses to which the water-supply was put. This quantity should be taken as the flow of sewage of normal strength, and then be increased to a certain volume whereby the necessary dilution was attained, before the storm-overflows were allowed to come into action. Taking the figures given by the Author, and converting them into volumes of dry-weather flow taken at 30 gallons per head flowing in 12 hours, the following results were obtained:— The provision for the Southern system was equivalent to 4 volumes, that for the Western to 6 volumes, that for the Marrickville to 6 volumes, that for the Manly to 3·8 volumes, and that for Parramatta to 3·67 volumes. It would be interesting to know what was the relative strength of the sewage in these several cases, when it was diluted to the full extent provided Mr. Priest.

Mr. Priest. for. The Author stated that the reticulation-sewers were designed to carry the maximum flows when between one-half and three-quarters full. This custom had formerly been adopted generally, but later practice had departed from it, and there did not seem to be any good reason why a pipe should be made of such a size that it would never be more than three-quarters full. Pipes which were filled by the maximum flow worked under better conditions at minimum flow. He noticed that the Author adopted a system of drop-pipes and tumbling-bays down the shafts for taking the sewage from the shallow to the deep sewers, and he would like to know whether the drop-pipes were vertical or inclined, as he had found in his own practice that in such arrangements it was much better to incline the pipes even if the angle with the vertical was very small. He would like to know why the manholes were built of conical form, as there did not appear to be any advantage from this shape, but some disadvantages. The sides of the excavations would, as a general rule, be made vertical, and therefore the outsides of the manhole walls, being built of concrete would have to be timbered for construction. For passage up and down within the manhole, vertical walls were much to be preferred to conical ones. The concrete, of which much use had been made throughout the system, was referred to as being rendered in many cases. He would like to know whether this meant that a face of mortar had been rubbed on to the surface of the concrete after it was dry. This method, which at one time had been customary, seemed to him to be one in which good results were most difficult to obtain, and for this reason he had discarded it, and now had exposed faces of all concrete made of fine material laid at the same time as the rest of the concrete, so that the whole mass set together and became one block.

Mr. Scudder. Mr. Frank Scudder, of Manchester, observed that in Table XIV. of Mr. Davis's Paper (p. 169) the carbonic acid figure of 128·9 had no apparent value, inasmuch as no discrimination was made between free carbonic acid and that which was in combination with the bases of the mineral constituents of the effluent. It was stated in the Paper that the sewage was treated with lime at the rate of 1 ton per million gallons. There would therefore, in all probability, be free lime in the effluent—a condition favourable to the formation of carbonate of lime in the pores of the filters. It appeared to him that the presence of carbonate of lime in the filters was due more to the chemical treatment, and to the subsequent bacterial and chemical reactions that took place in the

filters, than to the presence of shells, as suggested by the Author. The absence of nitrates, and the presence of a somewhat large quantity of nitrites in the effluent, was characteristic of a lime treatment. Without the analysis of the mineral constituents of the effluent the acidic figures given in the Paper were of little value. Mr. Scudder.

He considered that the Paper by Mr. Naylor was open to severe criticism from a chemical and biological point of view, but that it would not be desirable before a society of engineers to enter into a purely scientific discussion as to the action of bacteria on starch and allied compounds, notwithstanding the numerous investigations which had been made into the chemical and physiological relations, and the modifying external factors of temperature and acidity, concerned in the action of the diastatic ferment of bacteria in the transformation of starch. The Paper was not based on any scientific foundation, and could only be discussed as a practical contribution to an important subject. The main point brought forward was the statement that putrid sewage-sludge had the effect of preventing the souring almost completely in liquors containing starch or starch-products. In support of this statement the Author referred to a trial made with starch, and the results obtained were shown in Table I. of the Appendix (p. 181). The analytical figures given in that Table did not indicate appropriately the changes which had been brought about in the liquid during the period of standing, and there was no evidence to show that "souring" of the liquid had been prevented. His experience of the effect of adding sewage-sludge to starch-liquor was that invariably the "souring" of the liquid was increased and not prevented. The results in the Table (p. 236) were given in support of the assertion.

Apart from the question of producing acidity in the starch-liquor, the quantity of sludge produced, and its manipulation, had to be considered; and when it was stated that a trial made with starch, using the proportions given in Table I. had produced 40 per cent. of sludge, that was to say, 40 volumes of sludge were produced for every 100 volumes of starch-liquor used, and that a large portion of the starch was found unchanged in the sludge, the value of the results of the trial described at p. 172 was considerably modified. The volume of putrid sewage-sludge proposed by the Author to be used in proportion to the volume of trades waste to be treated was excessive, and the Author did not refer to the disposal of the putrid sludge which would accumulate on the manufacturer's premises. The analytical figures given in the

Mr. Scudder.

—	Acidity of Liquid in terms of H_2SO_4.			
	At Start.	Volatile in Steam after 5 Days standing.	Fixed after 5 Days standing.	Total after 5 Days standing.
		Grains per gallon.	Grains per gallon.	Grains per gallon.
1. Starch liquor alone, 2,500 cubic centimetres (10 lbs. starch to 50 gallons water) . .	Neutral	10·3	4·9	15·2
2. Starch liquor, 2,500 + 25 cubic centimetres putrid sewage-sludge	Neutral	14·2	6·4	20·6
3. Starch liquor, 2,500 + 50 cubic centimetres putrid sewage-sludge	Neutral	23·5	5·9	29·4
4. Starch liquor, 2,500 + 75 cubic centimetres putrid sewage-sludge	Neutral	32·8	4·4	37·2

Tables of results were open to criticism. For instance, in Table II. the filtrate contained 15 per cent. more suspended solids than the raw liquid treated. It was only "free" alkalinity that was removed, which was a very different thing from total alkalinity, and the Table did not make this point clear. Moreover, after standing for one week the alkalinity of the kier-liquor was only reduced from 8·6 to 5·8, being a reduction of 32·5 per cent., while the filter was called upon to deal with 67·5 per cent. of the alkalinity. The Author admitted that the nitric nitrogen figure, viz. 37·2, was phenomenal, and it might be of interest and value if he could throw further light on the conditions that had existed at the time when such a high figure was obtained, because the value of a so concentrated solution of nitrate could not be overlooked. With regard to the analytical figures given in Table III. there was no evidence to show how much free chlorine was present in the crude waste, and a quantitative definition of the Author's term "no inconsiderable amount," in his reference to the admission of bleach-works waste to the sewers at Burnley (p. 176), was required before the effect of chlorine could be discussed. It was scarcely a fair statement to say that for some three or four years before July, 1900, Messrs. Peel, Tootal & Co. had struggled with precipitation-tanks and ordinary continuous-flow filters without success. Such a statement might lead to the assumption that efficient purification could not be brought about by chemical precipitation and subsequent filtration; but the true reason for the non-success of the firm's struggles in the past was,

he ventured to say, to be found in the Author's statements, made elsewhere,[1] that at this mill very little had been done, and what had been done had been the result of continual worrying, and had been executed in a very unsatisfactory manner, the tanks and filters being small and negligently used. When the proceedings referred to by the Author had been instituted under the Rivers Pollution Prevention Act, the firm had not had a sufficient area of filters; leakage through the tank-bottom had not been remedied, no precipitants had been in use, and the tanks had been seldom cleaned.[2] On the 15th November, 1900, an order of the County Court had been obtained against the firm to carry out requisite works within a period of between three months and six months, but on the 8th November, 1901, the Author had reported to the Joint Committee[3] that— Mr. Scudder.

"Since November 1900, the tank accommodation has been about duplicated, and the shell of a filter constructed, but these have not received due attention; owing to inferior brickwork and masonry the tank walls have collapsed on one or two occasions, and the filter-shell is only partially filled with material. The beneficial effects of both tanks and filters is largely annulled by the presence of large volumes of clean wash-water which is allowed to mix with the crude waste because of the expense entailed in separating it. This state of affairs has been pointed out to the firm on several occasions, and I have now to recommend that they be advised that unless the filter is properly charged and put to work, with crude liquors separated from wash-waters, by the next meeting, application will be made for penalties."

He must leave the Author to reconcile the description of the installation made many months ago, and given in the Paper, with the position in November, 1901, as shown in the Author's official communications to the Ribble Committee, which were printed and available to the public. With regard to the treatment of brewery-waste, there was no evidence adduced by the Author to show that "souring" of the liquor did not take place when sewage-sludge was added to beer and allowed to stand for several days. He had found that acidity was produced; and in one experiment, where 3 volumes of sewage-sludge had been added to 100 volumes of beer, the acidity had risen from 70 grains sulphuric acid equivalent per gallon of liquid after standing one day, to 138·6 grains after standing three days, and to 313·6 grains after five days, when the smell of acetic acid had been pronounced. It was a pity that the Author had not brought his results up to date,

[1] Proceedings of the Ribble Joint Committee, 1898, p. 240.
[2] *Ibid*, 1900, p. 18. [3] *Ibid*, 1901, p. 256.

Mr. Scudder. and it would be interesting to hear what progress had been made with the installations which had been in process of construction when the Paper was written.

Mr. Selfe. Mr. NORMAN SELFE remarked that Mr. Davis's Paper suggested a great deal to one who, like himself, had seen the construction of the old Sydney sewers referred to at p. 121, but he would confine his observations to one or two points only. As the Paper was not accompanied by any schedules showing either current or past rates for excavation, brickwork or masonry, it was possible that readers of it outside Australia might be misled if they divided the total expenditure either by the acreage or by the population served. In order to do justice to the Sydney work, if any comparison was to be made with English or Continental sewage systems, the cost of work in Sydney must be taken into account. For instance, the double-pressed bricks in the Bondi sewer had cost about £6 per thousand; whereas he had understood at the Severn Tunnel, which he had visited at the time the Bondi sewer was under construction, that the bricks there were costing only 15*s*. per thousand. Owing to various causes the brickwork of the Tempe aqueducts had cost over 50*s*. per cubic yard at the time such work in England could have been done for a much smaller sum. Although prices had varied very much, the average during the whole course of construction of the works referred to in the Paper could not be taken as less than the following:—Plain brickwork in cement, 35*s*. per cubic yard; double-pressed brickwork in cement, 70*s*. per cubic yard; excavators (in tunnel) 8*s*. per day (8 hours); bricklayers, 11*s*. per day; masons, 11*s*. per day; cement, per cask of 4 cubic feet, 11*s*. The pumping-station, described at p. 139, had been the subject of a good deal of criticism on account of the double transfer of power (transmitted electrically in the first instance, and then transformed to air-pressure) to work the Shone ejectors. It had been contended that the air should have been compressed at the power-house and that air-mains should have been laid down; or else that a hydraulic system should have been adopted, in which case the high-pressure water-mains would have cost less and required less attention than the electrical conductors. To anticipate criticism at the antipodes of Sydney, it might suffice to say that the opportunity which this scheme afforded for making comparisons with the direct electric transmission of power to the pumps, would alone have been ample justification for the experiment—even had the results been less satisfactory than was the case. At the time of the construction of the old sewers nothing but common and very porous hand-made bricks and a

poor class of masonry had been available. When the new sewerage works had been started under the late Mr. Bennett, 25 years later, Sydney had been able to show as good bricks and as high-class masonry as any city in the world. In the desire that nothing but the best work should be put into the sewerage there had been now and then perhaps a little extravagance. At the same time it was the opinion of engineers entirely unconnected with the public service, that no branch of the Public Works Department of New South Wales had greater reason to be proud of the results achieved—as regarded both efficiency and permanence of character—than the branch of sewerage construction until recently under the direct charge of the Author. Mr. Selfe.

Mr. C. W. Smith considered that Mr. Davis, while dealing most ably and exhaustively with the sewerage systems of Sydney, touched but lightly on rainfall and water-supply. These subjects, so closely allied to the design of sewerage works, had suggested the following remarks. The dry-weather flow, which presumably should be based on the water-consumption, was set down at 75 gallons per head per day in the older portions of the scheme, and 40 gallons to 50 gallons per head per day for the outside areas; whereas the average daily consumption of water per head had remained practically the same for the past six years, in spite of the vast increase in sewer-connections. It might therefore be reasonably concluded that a maximum of 45 gallons per head per day was all that need be provided for, the extra water consumed during the dry season being used on gardens and streets. The Author pointed out, however, that it was owing to this liberal allowance for the dry-weather flow that many of the sewers had been able to meet the requirements of exceptionally heavy rainfalls. In the accompanying records (p. 240), kindly supplied by the Government Astronomer, Mr. H. C. Russell, C.M.G., F.R.S., it would be clearly seen how difficult it was to make provision for such extreme fluctuations, even though the area permitted to discharge into the sewer was regulated. In the principal storms which had occurred since 1869, the fall had varied between 0·13 inch and 1·74 inch per hour. During January 1901, three storms had occurred, in which downpours of 1·65 inch, 1·44 inch, and 1·48 inch per hour had been recorded respectively. The heaviest showers in each had been at the rate of 3·20 inches, 2·80 inches, and 6·40 inches per hour. The variation in the annual rainfall of Sydney was very marked. Taking the returns for the years 1839 to 1901 a maximum of 82·81 inches in 1859, and a minimum of 21·48 inches in 1848, were found. In later Mr. Smith.

Mr. Smith. years there had been in 1890 a fall of 81·42 inches; while in 1888 and 1895 there had been only 23·01 inches and 31·86 inches

RECORD OF HEAVY RAINS, SYDNEY, N.S.W.

Date.	Total Fall and Duration of Storm.				Heaviest Part of Storm.				Heaviest Shower.			
	Total Fall.	Duration.		Rate per Hour.	Total Fall.	Duration.		Rate per Hour.	Total Fall.	Duration.		Rate per Hour.
	Inches.	Hrs.	Mins	Inches.	Inches.	Hrs.	Mins.	Inches.	Inches.	Mins.	Secs.	Inches.
15 Oct. 1884	20·41	..		..	20·30	20	30	0·99	5·40	120	0	2·70
11 Feb. 1869	2·00	4	0	0·50	2·00	4	0	0·50	0·70	8	0	5·23
25 ,, 1873	11·90	11	30	1·03	2·20	1	0	2·20	1·50	20	0	4·60
5 ,, 1878	7·53	23	0	0·33	5·54	8	30	0·65	1·50	17	0	5·30
6 ,, ,,	3·35	24	0	0·14	1·20	1	20	0·90	0·23	3	0	4·60
8 ,, ,,	1·58	24	0	1·07	1·02	2	0	0·51	0·25	3	0	5·00
5 Apr. 1882	6·48	4	30	1·44	3·00	1	30	2·00	0·40	4	0	6·00
6 ,, 1884	6·45	20	0	0·32	5·63	12	0	0·47	1·00	10	0	6·00
13 ,, 1887	1·76	3	30	0·50	1·76	3	30	0·50	0·15	3	30	2·44
16 Dec. 1888	1·60	0	55	1·74	1·60	0	55	1·74	0·16	1	48	5·33
25 May 1889	2·28	19	0	0·12	..	..		..	..	..		..
26 ,, ,,	4·05	24	0	0·17	0·66	2	10	0·31	0·22	2	12	6·00
27 ,, ,,	4·60	24	0	0·19	1·10	1	0	1·10	..	..		..
28 ,, ,,	8·36	24	0	0·35	0·70	1	0	0·70	0·22	8	0	1·65
17 Feb. 1890	1·51	18	30	0·08	..	..		..	..	..		..
18 ,, ,,	3·21	24	0	0·13	2·53	3	0	0·84	0·22	3	45	3·52
19 ,, ,,	0·36	..		..	..	..		..	..	..		..
20 ,, ,,	3·25	24	0	0·14	2·60	7	15	0·36	0·275	3	0	5·50
21 ,, ,,	0·85	24	0	0·04	0·44	0	30	0·88	0·20	8	0	1·50
4 Mar. ,,	2·13	8	0	0·27	0·80	0	40	1·20	0·20	6	0	2·00
25 ,, ,,	5·66	24	0	0·24	0·66	1	45	0·38	0·22	12	0	1·10
2 May ,,	2·35	9	30	0·25	1·32	3	30	0·38	0·22	5	30	2·40
27 June ,,	2·57	13	0	0·20	1·76	3	15	0·54	0·35	10	0	2·10
28 ,, ,,	4·48	9	30	0·47	3·50	5	0	0·70	0·21	3	9	4·00
24 Feb. 1891	1·50	12	0	0·13	0·40	0	9	2·67	0·14	2	24	3·50
11 Jan. 1892	1·81	3	0	0·60	1·54	0	23	4·02	0·88	10	0	5·28
20 Mar. ,,	4·22	15	45	0·27	0·29	0	10	1·74	0·21	5	0	2·52
18 Dec. ,,	2·13	17	0	0·13	0·80	0	22	2·18	0·20	3	0	4·00
8 Mar. 1893	3·30	12	0	0·27	0·80	0	43	1·12	0·17	4	0	2·55
23 ,, ,,	2·17	17	0	0·13	1·00	1	0	1·00	0·22	3	0	4·40
4 June 1896	4·88	24	0	0·20	2·35	1	50	1·28	0·18	1	51	5·84
1 June 1897	2·66	8	15	0·32	2·00	4	45	0·42	0·20	4	22	2·75
23 May 1900	2·91	11	50	0·24	2·00	4	46	0·42	0·20	3	20	3·60
25 ,, ,,	3·26	22	0	0·15	1·44	0	45	1·92	0·20	3	45	3·20
19 Nov. ,,	4·23	24	0	0·18	0·95	1	0	0·95	0·08	2	9	2·24
20 ,, ,,	1·20	6	45	0·18	0·40	0	13	2·00	0·20	5	0	2·40
1 Jan. 1901	1·10	0	42	1·65	0·20	0	$4\frac{7}{60}$	2·80	0·40	7	30	3·20
2 ,, ,,	1·20	0	50	1·44	0·60	0	15	2·40	0·20	4	17	2·80
21 ,, ,,	2·60	1	45	1·48	1·80	0	25	4·32	0·20	1	53	6·40
28 Apr. ,,	3·67	4	0	0·92	2·40	2	0	1·20	0·20	3	30	3·45

respectively. The Nepean scheme of water-supply, propounded in 1869 under a Royal Commission and subsequently carried to

completion, was designed to supply 48 gallons per head per day to a prospective population of 500,000. This number was now reached, and was supplied from these works. A dry season, such as that experienced in 1895, when but 31·86 inches of rain had been recorded, taxed the present storage-reservoir to its utmost. To meet the prospective increased demand, an extension of the scheme, in so far as regarded storage, was now being considered by the Board of Water-Supply and Sewerage. Mr. Smith.

Mr. G. H. STAYTON observed that, having an intimate personal knowledge of the subject of Mr. Davis's Paper, he would like to express satisfaction with the Author's clear and interesting account of the extensive works initiated and practically carried to completion at Sydney during the past 20 years. He deemed it highly creditable to the Mother State of Australia that so excellent a water-supply (now averaging 44 gallons per head per day) had been provided for the capital city, followed by a comprehensive and effective system of sewerage and drainage; greatly to the advantage of the present and future generations. Indeed the health-statistics quoted by the Author emphatically demonstrated the value of the advantages thus secured for the inhabitants of Sydney and its extensive suburbs. The Author recalled the fact that the first scheme propounded for the main drainage of the city, and a limited portion of the suburbs, had been that of the Health Board. This proposal had been specially reported upon in 1877 by Mr. Clark, who, during his visit to the Australian Colonies in 1877 and 1878, had also reported upon the drainage and water-supply of various other cities and towns in Australia and in New Zealand. Mr. Clark's report on the drainage of Sydney was a highly interesting and instructive document and his recommendations had carried conviction. These works had been subsequently authorised by Parliament, and their construction had been nearing completion, when, in 1886, there had been a strong public agitation for the adoption of proper sanitary measures throughout the western suburbs, where typhoid fever and other preventable diseases had become alarmingly and increasingly bad. At this time he had become professionally associated with the sewerage of Sydney, inasmuch as the then Minister for Public Works, the Hon. W. J. Lyne (now the Hon. Sir William Lyne, K.C.M.G., Federal Minister for Home Affairs) had appointed him to investigate and report upon the sanitary condition and requirements of the suburbs of Sydney, and in due course he had submitted comprehensive schemes and Mr. Stayton.

Mr. Stayton. plans for the sewerage and drainage, not only of the western suburbs of Sydney, but also for North Sydney and Manly, at a total estimated outlay of £1,946,896. These schemes had been submitted to Parliament and to the various municipalities interested, and had been subsequently investigated at great length by the Parliamentary Standing Committee on Public Works, receiving unanimous approval; and in due course their construction had been authorised by Parliament. The Author had so clearly described the leading features of the various systems that Mr. Stayton would confine his remarks to the Western Suburbs systems and to the more important points he had had to consider and determine in devising the scheme. In the first instance he had made an inspection of the entire municipal areas, which covered no less than 31 square miles, and comprised nineteen boroughs or municipal districts. Much time had also been occupied by the staff placed at his disposal in surveying and levelling the area under consideration; in fact, it had taken nearly 2 years to thoroughly formulate the scheme. He had found that the physical features of the area to be sewered presented peculiar conditions, and, although favourable for the discharge of rainfall and storm-water from the surface, they rendered the question of sewerage unusually difficult to determine. The sanitary conditions had been terribly bad—slop-waters and other liquid refuse being allowed to flow into the surface channels at the sides of the streets, from which the filth eventually found its way into the natural water-courses and creeks. This condition of things had been most offensive, and in a hot climate like that of Sydney had created a great nuisance and pollution of the air. As the result of the preliminary examination of the district he had been enabled to omit certain areas from the sewerage scheme and so to reduce the actual drainage-area to 22 square miles. He had found that 5 square miles could be drained into the northern and southern outfall-sewers, but that the remaining 17 square miles of the western area necessitated an entirely new system, which could be made to discharge at Botany Bay. Various systems of sewage-disposal had been fully considered, but in the end he had had no hesitation in recommending, as the most practical, efficient and economical method, a comprehensive scheme upon the "partially separate" system, by which all sewage and a limited portion of the surface-water would be removed by the intended sewers to a sewage-farm or filtration-area of more than 300 acres in extent, at the head of

Botany Bay. The nature of the soil and the situation of the site rendered this area peculiarly suitable for the purification and utilization of sewage. It consisted of a fine and very porous drift sand, and presented an average surface sufficiently above high-water level to afford effective purification. It was a satisfaction to note the Author's remarks, that no nuisance or damage to health had arisen from the operations at the farm, also that a substantial income was derived from the crops raised and the animals reared. He well remembered that excellent vegetables had been grown on this farm when he was in Sydney. The allowance he had made in 1888 for prospective population had been based on the then existing conditions of increase, which as the Author stated, had led him to reasonably expect a corresponding increase in the near future. It must, however, be obvious that he could not then foresee the serious financial crisis which was to occur in Australia about 1892–3, and which for a time had almost paralyzed building operations in the western suburbs of Sydney and in the large cities of Australia. The depression had taken several years to overcome, and had naturally checked the rate of increase. He ventured to think that any engineer might be excused for being below the mark in his allowances under such unlooked-for and far-reaching effects as had been brought about by the banking and financial crisis referred to. Having determined upon the drainage-area, method of disposal, position of outfall, prospective population, and the quantity of sewage and rainfall to be carried off by the sewers, the most important object to attain in devising the proposed scheme had been to provide for the removal of as much sewage as practicable by gravitation, thus reducing the amount of pumping to a minimum. Each additional foot in the height or level of the outfall-sewer, at the intercepting-chamber at its head, became an important factor. In adjusting the line and levels of the outfall-sewer, he had had to consider the Illawarra Railway and certain main roads, also the crossing of Cook's River in such a manner as not to interfere with navigation. These conditions had been duly provided for by the outfall-sewer adopted. Its length was 11,700 feet, and the invert-level at its upper end was fixed at 15·88 feet above datum. In determining the form and dimensions of the outfall-sewer, he had come to the conclusion that it would be undesirable that it should consist of one large sewer only. The dimensions of such a sewer must have been at least 9 feet in diameter, which would have meant a loss of about 4 feet in level at the intercepting-chamber, thus greatly Mr. Stayton.

Mr. Stayton. restricting the gravitation area. He had therefore decided to provide for three sewers, each 6 feet in diameter, and had recommended that two only should be constructed in the first instance, provision being made for the third when the conditions demanded the additional carrier. As the Author had fully described this work, and had illustrated it by drawings, he need not further refer to it. Above and beyond the intercepting-chamber at Marrackville, the drainage-areas or natural water-sheds requiring to be intercepted were somewhat numerous. This was due to the fact that the whole district consisted of ridges and valleys; the watersheds discharging into various bays on the Parramatta River on the north, and by creeks and water-courses to Cook's River on the south. With a view to effective extension of the gravitating system as far as possible in the direction of Strathfield and Homebush, it had been absolutely necessary to reach the extreme points in the most direct manner in respect to lines and levels. To effect this, and to provide for the interception of the sewage from Petersham, Leichhardt and other districts, had necessitated the construction of the greater part of the main intercepting-sewers in tunnel. The positions and points of termination of the several main sewers and sub-mains had thus been determined with a view to facilitate and cheapen the construction of the necessary subsidiary sewers in each of the natural watersheds. The 37½ miles of main and branch sewers had been designed to be constructed in straight lines as far as practicable, of such a form as to give the greatest hydraulic mean depth, and consequently the greatest velocity or scouring-power during the periods of minimum dry-weather flow. The gradients and steps at the various intersections had also been so adjusted and regulated as to ensure self-cleansing. According to the Thirteenth Annual Report of the Metropolitan Board of Water-Supply and Sewerage, submitted to the State Parliament of New South Wales on the 10th December, 1901, he learned that there had then been 515 miles of sewers under the control of the Board, and that 75,416 houses were connected therewith, representing a population of 370,000. With regard to the Author's statement that the cost of the works to December, 1899, had been £3,356,907, and his estimate that the outlay would ultimately be increased to £4,115,713, the former figures were practically confirmed by the above-mentioned Annual Report, which stated that the actual capital expenditure to 1901 had amounted to £3,280,427. As the existing population numbered about 500,000, it might be

considered that this was an excessive outlay, amounting as it did to over £6 per head. The completion of the entire scheme, however, would provide for a prospective population of 1,200,000, in which case the cost per head would thus be reduced to about £3 10*s.* There were important factors, however, which had materially increased the outlay, *e.g.*, (1) the excessive provision for suburban roads and streets requiring to be sewered, the ratio of the street mileage to the population being largely in excess of that obtaining in cities and towns in other parts of the world; (2) the greater cost of labour and materials in Sydney in comparison with current rates in Europe. In his report to the Government on the sewerage of the western suburbs he had drawn special attention to these points, feeling that some explanation was desirable. From the inception of the works under discussion until recently, the changes which had occurred in the administration of the Sewerage Department had been so remarkable that a few words in reference thereto might not be uninteresting from a professional point of view. Owing to the peculiar system formerly adopted by the Government there had not been for many years a separate office created as Engineer-in-Chief for Sewerage, but the duties had been somehow tacked on to the office of Commissioner for Roads and Bridges. Indeed, the late Mr. W. C. Bennett, M. Inst. C.E., who had thus supervised the construction of the city outfall-sewers from 1880 to 1889 had not actually received the pecuniary recompense promised for his extra services, and had only received certain compensation for those services on retirement shortly before his death in 1889. He had been succeeded by Mr. R. R. P. Hickson, M. Inst. C.E., for a few years, before that gentleman had taken the non-professional position of Under-Secretary for Works. When Mr. Hickson had been thus transferred, the Author had succeeded him as Sewerage Engineer, but about a year ago, on further departmental reorganization, Mr. Davis had likewise left the professional branch to become Under-Secretary for Works. Evidently this branch of engineering seemed to have furnished a remarkable qualification for the Under-Secretaryship of the Public Works Department. In conclusion, it was a personal satisfaction to learn from the Author, and from other sources of information, that the sewerage systems under consideration had in every way fulfilled the expectations raised, and had added vastly to the comfort, convenience and health of the large population resident in the foremost southern city of the British Empire. Mr. Stayton.

Mr. Tatton. Mr. R. A. Tatton remarked that Mr. Naylor's Paper was of special interest, as it called attention to the treatment of trades waste, which was a subject of great importance at the present time, owing to the efforts which were being made for the purification of rivers. The system proposed, namely, the introduction of sewage matter in order to induce septic action in the tanks, might be of value for the treatment of brewery-waste in order to counteract the acid fermentations which took place and which were difficult to deal with; but for dye-works and bleach-works waste its adoption was of doubtful expediency. The cause of nuisance arising from septic tanks was at present imperfectly understood; but the evidence seemed to point to its occurring when the flow of sewage through the tanks was unduly prolonged. From 20 hours to 24 hours seemed to be the maximum time of flow which should be allowed; it was therefore not unreasonable to expect that tanks holding 3 days' supply, as advocated by the Author, would cause trouble, which would be a serious matter if the tanks were situated, as they often were, in close proximity to the works. With regard to the treatment of kier-liquors at Mr. John Stanning's works, an alternative method to that proposed, and one which had been adopted in some instances, would be to collect these liquors in a separate tank and to distribute them gradually over the day's flow, the object in this being to neutralize the alkali by means of the acids used in the other processes. They were highly concentrated and difficult to deal with by themselves, but their volume was only about 4 per cent. of the total, and if they were thus distributed no difficulty should be found in the treatment, if the capacity of the tanks and filters was proportionate to the volume. In the description of the treatment adopted by Messrs. Peel, Tootal and Company, it was stated that the firm had struggled with precipitation-tanks and ordinary continuous-flow filters without success, but the size of the tanks and filters was not mentioned, nor whether there had been any special reason for the non-success of the treatment; it would be interesting to have this information. Later, it was mentioned, the capacity of the tanks had been increased to three days' flow and the septic treatment had been adopted. Was it to be inferred from this that treatment in tanks of this capacity would not be successful unless septic treatment, with its accompanying filter 11 feet in depth and revolving sprinkler, were adopted? Surely this was rather an alarming prospect to put before manufacturers. Another item of expense in connection with the deep coarse filters proposed

was the necessity for raising the temperature of the liquid turned on to them; as it was doubtful whether, if the temperature was not raised, the biological action in the filters would be sufficiently maintained. This raising of the temperature was done by means of steam. In the case of sewage the rise amounted to between 5° and 10° F. according to the time of the year; and the amount of coal required to raise the steam for this purpose was, according to Mr. C. J. Whittaker's evidence before the Royal Commission on Sewage Disposal,[1] 10 cwt. to raise the temperature of 1,000,000 gallons by 1° F. Bleach-works waste being considerably colder than sewage, it would probably be safe to take 10° F. as the average amount by which the temperature would require to be raised. On a volume of 500,000 gallons per day this would amount to a coal-consumption of nearly 800 tons per annum. In addition to this, where works were situated not much above the level of the stream, there would be the extra cost of pumping. There was, however, ample evidence in the Mersey and Irwell watershed that the waste from bleach-works might be satisfactorily treated with much less costly appliances. If the treatment was properly attended to, and if the kier-liquor was distributed and the tanks were cleaned out regularly, a tank-capacity of from 1 day to 1½ day's flow should be ample, if followed by filtration through graded filters, to produce an effluent which would contain no suspended matter, would not putrefy, and would not cause a nuisance even if discharged into a small stream. Brewery- and distillery-waste could not be placed in the same category as the waste from print- and dye-works, bleach-works and paper-works, and Mr. Naylor's Paper was most valuable in presenting a possible solution of the difficulties in connection with the treatment of the former. Mr. Tatton.

Professor W. H. WARREN considered that Mr. Davis had prepared a valuable Paper, giving a clear and concise account of the sewerage systems of Sydney and its suburbs. He had at various times been associated professionally with portions of these works, and for the last 20 years he had had special opportunities of studying their progress and development. The several sections which had been constructed from time to time appeared to him to represent very fairly the knowledge and experience in sanitary science and engineering available at the time of their construction; and, taken as a whole, the works might well claim to be one of the best Prof. Warren.

[1] "Interim Report of the Commissioners," &c., vol. ii. p. 282. London, 1902.

Prof. Warren. modern examples of the sewerage of cities and towns. With regard to construction, considerable attention had been given to the quality and suitability of the materials used, and their examination had included, in addition to the ordinary tests, several series of investigations, which he had conducted in the laboratory of the University, on the strength of various kinds of brickwork in piers and beams; also tests of concrete carried out on large-sized specimens of beams, slabs, and pipes made on the Monier system, subjected to tension, compression, and cross breaking. The adoption of the Monier system, he considered, was one of the features of the later constructions, more especially in large drain-pipes, culverts and conduits; there were also examples of aqueducts carried over creeks and low-lying grounds by a series of arches, which had a light and graceful appearance. The main Northern sewer, by means of which the sewage was discharged into the ocean at Ben Buckler Head, was interesting chiefly on account of the novelty in the design of the outlet-works, and also the difficulties encountered in constructing the main sewer through about 60 chains of wet drift sand. During southerly, south-easterly, or easterly gales, the waves on the coast attained enormous heights, and struck the coast line and the cliffs with extraordinary force; so that the design and construction of the outlet-works had necessitated careful consideration. The two outlet-channels, which diverged from the chamber situated at a distance of 200 feet from the outlet, were so located that the sea, except on rare occasions, never entered both outlets at the same time, and consequently there was generally a free discharge of sewage by at least one of the channels. The stream of sewage flowed out to sea in a south-easterly direction, where its effect was soon lost in the mass of ocean water. The force of the sea rushing into either of the channels was deflected and destroyed by means of the massive weir-wall in the chamber, and the outlet-works generally were simple, massive, and effective. He thought the methods adopted for raising the sewage from the various low-lying areas to the level of the intercepting-sewer were well worthy of study, more especially the one in which each of the seventeen low-lying areas adjoining the harbour was supplied with electrically driven motors, driving duplex or triplex pumps; the electricity being supplied from the tramway power-station to a central controlling pumping-station, from which the energy was transmitted to the various sub-stations. He considered that the economy realized in this case was due to the low cost of

the electrical energy supplied to the controlling-station; to the high efficiency of the motors driving the pumps, as compared with other methods of driving; to the small loss of energy in the electrical transmission from the controlling-station; and also to the convenience of the arrangements by means of which the level of the sewage in the wells of the various sub-stations could be ascertained, and the motors and pumps be controlled from the central station. He considered that the system of ventilating the sewers adopted in Sydney, in which numerous induct and exhaust shafts, surmounted by cowls, were distributed over the whole system, was a very satisfactory one, and rendered it possible to renew the air in the sewers so frequently that it had practically the same composition as the external atmosphere. The various methods of sewage-disposal adopted were well suited to the special conditions existing in the various sections dealt with. Thus the northern section discharged into the sea, and the southern and western on to a sewage-farm; while in the North Sydney system the most convenient treatment consisted of straining, precipitation with lime, and filtration of the effluent before discharging it into the waters of Middle Harbour. The sludge was formed into cakes by means of presses, mixed with coke breeze and burnt in destructors. Again, at Rookwood Asylum, at Willoughby and at Chatswood, a more modern method was adopted by which the sewage was treated by a combination of septic tanks and bacterial filters. In all of these the results had been satisfactory. Prof. Warren.

Mr. H. Gilbert Whyatt remarked that he had been much interested by Mr. Davis's account of a work of municipal engineering of such large dimensions, carried out so thoroughly. An engineer who had the opportunity of carrying out such a work was to be congratulated, and a city of the size of Sydney was to be congratulated on having the courage to face so large an expenditure on sewerage. He would like to know whether the 1*s.* rate mentioned at p. 133 had been charged at the outset upon each district as it was connected up; or whether a small rate had been charged upon the whole of the ratepayers of the city, which had grown with the increased expenditure until it now reached 1*s.* in the pound. He noticed that in the older parts of the city the rainfall had been taken at ½ inch or 1 inch per day, while in other parts it had been assumed at 2 inches per day for a catchment of 200 square feet per head. It would be interesting to know the reason for the difference in stating the rainfall, as he could Mr. Whyatt.

Mr. Whyatt. not believe that the fall varied in different parts of the city. It would have been better, in his opinion, to have given a fixed rainfall of, say, 1 inch per day, and then to have stated whether the whole or a certain fraction of it reached the sewers, the rest of the rain being presumed to fall on gardens or on fields, and to be lost by percolation into the ground. It was stated that the average daily water-supply had increased to 42 gallons per head; but in all the calculations 75 gallons of sewage per head per day were provided for. It must be admitted that the ratio of sewage to rainfall was always fractional, and the fact of the quantity of sewage being almost doubled hardly affected the size of the sewer; but there ought to be some explanation of the difference between the water-supply and the sewage. If subsoil-water accounted for the difference, how was the quantity arrived at, and how was it admitted to the sewers? He commended the introduction of tall shafts for ventilating the sewers, but noticed that they were provided at the rate of only ten per mile. The number recommended in 1878 by the Chief Engineer to the Local Government Board (the late Sir Robert Rawlinson, K.C.B., Past-President Inst. C.E.) was eighteen ventilation-openings per mile, manhole-covers being used as both inlets and outlets. He would like to know whether the small number of ten per mile kept the air of the sewers so pure that workmen were not inconvenienced when having to work below the surface for 3 or 4 hours consecutively. The Author mentioned that the main and lateral sewers were provided with shafts of much larger diameter than 6 inches, and from Table XV. it appeared that there were thirty-six 9-inch shafts and one 16-inch shaft, besides fifteen other exhaust shafts. He would be glad to know whether there had been any attempt to make the diameter of the shafts proportionate to the unfilled area of the sewer, and if so, what proportion had been adopted. Also, whether the water-sprays mentioned in connection with the ventilation of the sewers were still in use. He would suggest that a diagram should be added giving details of the large inverted siphon at George Street West, which would be both interesting and useful to other municipal engineers.

Davis. Mr. Davis, replying in writing to both the Discussion and the Correspondence, remarked that he would like to express his thanks to the President, to Sir Alexander Binnie, and to other speakers and correspondents for their appreciative remarks upon his Paper, and to Mr. Darley for his kindness in giving useful information on

points which had arisen in the discussion. It had also been gratifying to him to see that some of the local engineers (unconnected with the Public Works Department), whose opportunities of judging had been very full, had commented in favourable terms upon the works carried out in Sydney. He might mention in particular the remarks of Mr. Griffiths—who, as Principal Assistant Engineer for Sewerage under the Metropolitan Board of Water-Supply and Sewerage, had had special responsibility in connection with the maintenance of the works carried out by the Author and his predecessors—in regard to the substantial construction of the works generally, and the fact that no expenditure had been incurred by the Board for any repairs to them. Mr. Davis.

Comment had been made by Mr. Latham on the efficiency of electrically driven pumps being not higher than 56 per cent., and he seemed then to proceed to make a comparison based upon figures contained in Tables representing pumping under two different systems, viz., electrical pumping and the Shone system. As to the efficiency of 56 per cent., which was that obtained with the electrical pumps, this was deemed satisfactory considering the low lifts; indeed, he doubted whether higher efficiencies could reasonably be expected under the same circumstances. With regard to Mr. Latham's remarks as to the capacity of the ejector as given in Table X., the figures given as the amount lifted by the ejector were not the result of actual measurement.

Several speakers had referred to the driving of air-compressors by electricity as an undesirable method, and Mr. Darley had already explained how it had happened that in this case electricity had been adopted. The public sentiment and convenience had run strongly against the use of steam in the locality, and the establishment of a power-house for tramway purposes within a comparatively short distance had enabled the Department to obtain electrical energy very cheaply; this had relieved the Department of the trouble and responsibility of setting up a generating-station, and the total efficiency was greater than could have been obtained otherwise. The air-compressor as a piece of apparatus had come in for unmeasured condemnation by some speakers, while others had maintained that it was not an inefficient machine. Whatever were its defects, it was at present an indispensable part of the Shone system, and, as modified by the Department in the present instance, it was working satisfactorily. The plant had been running for more than three years, and nothing had been spent in repairs except such little matters as could be attended to by the maintenance

Mr. Davis men and the men in the station. The Shone system had been adopted in one only of the many low-level districts connected with the Sydney sewerage, and in this district it had been decided upon before electricity at a low cost had been obtainable. The district, too, was one in which the conditions were favourable to the system. The land being flat, it had been easy to arrange so that the lifts from all the stations were approximately equal. One great advantage of the use of electricity, not alluded to in the oral or the written discussion, was the economy with which it could be applied where the lifts varied considerably. Under such conditions the use of compressed air became expensive, as the ruling pressure was determined by the highest lift in the circuit of stations.

With regard to Mr. Hanssen's remarks on the tests of the efficiency of the Shone ejector carried out by Professor Unwin some years ago, in Professor Unwin's book [1] it was mentioned that the efficiency obtained in one test had been 42 per cent., and in another 38 per cent., or an average of 40 per cent. It should be remembered, however, that the efficiency obtained at Sydney was the result of experiments on a very much larger scale, and he did not think that higher efficiencies had been obtained elsewhere under similar conditions. The "combined efficiencies of motors and pumps" given in the Paper were the guaranteed efficiencies of the motors and pumps when actually doing the specified quantity of work. With regard to the use of centrifugal pumps instead of plunger-pumps where the motive power was electricity, it should be remembered that the plant under discussion had been designed about five years ago; improvements which had since taken place in centrifugal pumps made them much more fitted for the work of pumping sewage by electric power, and in the future, no doubt they would supersede plunger-pumps for this purpose. Where opportunity offered, the Department was now introducing the centrifugal pump, but at the time no tenders had been obtainable for the supply of these pumps with a sufficiently high guaranteed efficiency; in fact, as Mr. Darley had shortly said, the argument at the time had seemed to be in favour of plunger-pumps, and they had consequently been adopted for the scheme.

Exception had been taken to the manner in which the allowances for rainfall in the sewers had been stated, but he did not think that any real confusion could have arisen, though the manner

[1] "On the Development and Transmission of Power from Central Stations," p. 209. London, 1894,

of statement had varied. Surprise had also been expressed at the fact of different allowances having been made in different districts, which the speakers thought could not differ in climatic conditions. It was a curious fact, however, that on the southern slope of the main ridge at Sydney the amount of rainfall was sensibly greater than on the northern slope. It was obvious, too, that equality of rainfall was not the only factor to be considered, as the degree of slope and character of surface had a large influence. Mr. Davis.

In reference to Mr. Bryce's remarks, he might say that where 2 inches of rainfall per hour had been taken, it had been assumed, in designing storm-water channels, that 50 per cent. of that fall would reach the channels. Each watershed had been studied separately, and the allowances had varied between $1\frac{5}{8}$ inch per hour actual carrying capacity of channel, down to $\frac{1}{3}$ inch per hour channel capacity. Other questions raised by Mr. Bryce as to intensity of rainfall-discharge during the period of flow, etc., could not well be answered in a short reply, and were of sufficient importance to form the subject of a short Paper. On the question of rainfall Mr. C. W. Smith's remarks were of great interest. With regard to difference in methods of statement (*e.g.* as to allowances), and other differences, which seemed to have been regarded by some of the speakers as inconsistencies of practice, he would like to say that it was seldom, if ever, that a Paper was written describing the progress of sewerage works covering so long a period of time. Between the time when the sewerage of Sydney had been first comprehensively studied and advised upon, and the date of his Paper, about a quarter of a century had elapsed. The changes and developments in many branches of sewerage engineering during that time had been rapid and remarkable, and the sewerage of Sydney and its suburbs was a kind of epitome of those changes and developments; no doubt it bore also the impress of the various individualities of the controlling engineers.

As to the cost per head of Sydney sewerage compared with that of European cities, Mr. Darley and Mr. Norman Selfe had clearly explained the causes which had operated to make the work costly in Sydney, and he did not know that he need add anything to what they had said. In regard to Mr. Martin's comments on the cost of the septic tank at Rookwood, it should be observed that when this was designed there had been little or no data available, and many things had been put in so that the works could be run in various ways, which increased experience had since shown to be unnecessary. It should not be forgotten, too, that the cost of

Mr. Davis. such installations varied rapidly with the size: for instance, for 1,000 persons it was now found possible to construct them at a cost of about 32*s*. per head, while for 3,000 persons the cost diminished to about 20*s*. per head.

Sydney being fully committed, for the greater part of its low-level sewerage, to a system of electrical pumping, in which electric motors had to be placed underground, he might say that the fears expressed by some speakers as to the risk of such an arrangement did not seem at all likely to be realised there. So far, no difficulty has been experienced in keeping the concrete chambers or iron cylinders perfectly dry and well ventilated, and entirely suitable as receptacles for the machinery. As a rule small buildings were erected over them, of which they formed a kind of cellar.

The principal reason why he had not discussed the question of house-connections, referred to by Mr. Cuthbert, was not that he underestimated the importance of it, but that in Sydney and its suburbs the work of house-connections was carried out under by-laws framed by the Metropolitan Board of Water-Supply and Sewerage, a Board distinct from the Public Works Department, in which Department, as Engineer-in-Chief for Sewerage Construction, he had had the control of the design and construction of all main works, and in some districts had put in the reticulation also; though, as a rule, the reticulation-sewers had been laid by the Board. A few details of the practice in house-connections might, however, be given.[1]

The system of ventilation by means of openings in the man-hole-covers, which Mr. Cuthbert had mentioned was in use in Christchurch, N.Z., and which was still adhered to in many English towns, was not in use in Sydney; as pointed out in the Paper, it had been abandoned there many years ago on account of its inefficiency and the nuisance arising from it. In Sydney, in addition to the ventilators, which formed a part of the house-connections alluded to above, pipes were carried from the man-holes to exhaust-shafts, which were carried on the walls of buildings. Mr. Cuthbert had remarked that the open gratings of man-holes did duty as fresh-air inducts, while private ventilators —which apparently he only placed where an internal water-closet was provided, or where the length of the connection exceeded 150 feet—acted as exhaust-shafts; and these ventilators were stated to

[1] *Post*, p. 257.

be 3 inches to 4 inches in diameter. With such lengths of connection, Mr. Davis thought a ventilator of this size would be of very doubtful efficiency. After recently visiting many English towns, in which the ventilation was carried out very much as Mr. Cuthbert had described, he felt more than ever satisfied that the system adopted in Sydney was preferable. Mr. Davis.

As to gradients of reticulating pipe-sewers, in Sydney the aim was to obtain a velocity of flow of not less than 2½ feet per second in the sewers. Six-inch pipes were generally laid on gradients of about 1 in 100 to 1 in 140, 9-inch pipes about 1 in 200 to 1 in 260. Steeper gradients were, of course, used where obtainable.

With regard to Mr. Priest's remarks as to jumping-weirs, the circumstances in Sydney were somewhat peculiar. In parts of the city there had existed a number of old sewers on the combined system, and as it had been absolutely necessary to intercept the dry-weather flow, and undesirable to do more than this, jumping-weirs had been resorted to. They differed from those generally used, in so far that when they were fixed in place they could be regulated to any position, so as to ensure the interception of the whole of the dry-weather flow. As to the dilution of sewage before the storm-water overflows come into action, he might say that in every case the storm-water discharge was into a large body of salt water, and the dilution was great; for instance, as Mr. Griffiths pointed out in speaking of the western system, in the overflows discharging into Woolli and Muddy Creeks, the ratio of rain-water to sewage was 35 : 1. In connection with the drop-pipes and tumbling-bays, the drop-pipes were vertical. The drop was into a water-cushion, and the water-cushions in deep shafts were never more than 40 feet apart. The building of man-holes in a conical form was only done to a depth of about 13 feet; where the depths were much greater than that, there were square chambers with shafts. As to the use of timbering, in practice it was not found advisable to put concrete immediately against the earth sides of the excavation, so that the back wall timbering was always necessary whether the walls of the man-holes were conical or vertical. The concrete was rendered, as stated in the Paper; the surface was always thoroughly soaked before rendering, and the rendering was put on in two coats. With exceedingly few exceptions, after several years the rendering was intact.

In reference to the carbonic acid figure, 128·9, referred to by

Mr. Davis. Mr. Scudder, it should have been stated in the first column of Table XIV. that of this amount 61·6 parts was carbonic acid combined with bases, and in the second column 55·44 parts was combined.

Mr. Whyatt was not quite accurate in stating that in all the calculations 75 gallons of sewage per head per day had been provided for. This had been the allowance in the earliest schemes. The difference between the water-supply and the sewage was not accounted for, as Mr. Whyatt seemed to suppose, by any necessity for making provision for a large supply of subsoil-water; as a matter of fact the amount of subsoil-water entering the sewers was comparatively insignificant. When the allowance of 75 gallons per head, however, had been fixed, there had been very little data upon which to make an accurate estimate of the amount then likely in the future to reach the sewers. The accumulation of data since that time had led to the reduction of this item, and in most of the schemes designed during the past few years 50 gallons per head had been considered sufficient. No doubt there was a small amount of leakage into the sewers, particularly into pipe-sewers, but this could not be wondered at when the large number of junctions was considered. Before house-connections were made the junctions were covered with disks, which could not be made as tight as a permanent joint, or the sewer-pipe would have to be broken in order to make the connection. The means of access of subsoil-water to the sewers decreased as these disks disappeared and gave place to the permanent joints of the house-connections.

With regard to the separation of rainfall and sewage, it might be stated that in some of the more recently designed schemes, such as Chatswood and Willoughby, the absolutely separate system had been adopted, and no rainfall whatever from the roofs or yards of houses was admitted into sewers. In the western system where the work of house-connection was rapidly approaching completion, it had been the practice of the Board to keep out rain-water as much as possible, and where owners desired to admit certain quantities of rain-water, this was done, if the Board approved, at the owner's risk and expense. The one-shilling rate referred to by Mr. Whyatt was charged at the outset upon each district in the western scheme as it was connected up. The same charge had also been found necessary in some of the later schemes in less densely populated suburbs. Within the area drained by the northern and southern systems, however, which comprised the city proper and the largest amount of highly-rated property, the rateable values

had been so high in proportion to the cost of the work that the rate charged was 7*d.* in the pound. Low-level pumping-areas, however, though within the city, were charged at the rate of 1*s.* in the pound. Mr. Davis.

The Water-Supply and Sewerage Board had made a series of experiments on ventilation, and the system based upon those experiments was such that the air in the sewers was changed about once in every hour. It could not be contended, therefore, that the number of openings (about ten per mile) was insufficient. As would be seen by referring to Mr. Griffiths's comments, the men in the sewers worked "with every comfort and with no ill effect upon their general health."

Complete details of cost of pumping and sewage-purification were not available at the moment. Mr. Griffiths had kindly supplied him with the following information:—The cost of purification at the Sewage Farm, Botany, receiving the sewage from the southern system, was about 20*s.* per 1,000,000 gallons. At North Sydney, where precipitation-works were established, the success of the septic system during the last two or three years had led to some modification of the works, and exact figures of the cost could not be given. The cost of pumping at two stations, viz., Marrickville Central Pumping Station and Double Bay Station for the year ending 30th June, 1901, was as follows:—

Cost of Raising 1,000 Gallons of Sewage 100 Feet High.

	d.
Double Bay	10·0
Marrickville	2·3

It should be pointed out that Marrickville was a large pumping-plant driven by steam-power, not yet working to its full capacity, and the cost would be still further reduced when the district was more completely connected. Double Bay was a comparatively small area worked under the Shone system, and the motive power of the air-compressors was electrical energy.

SEWERAGE OF SYDNEY, N.S.W., AND SUBURBS.

Details of Practice in Regard to House-Connections.

Material.—Practically the only pipes used are of the best glazed stoneware.

Sizes.—Nothing less than 4 inches in diameter is allowed for conveying sewerage, and in practice 4-inch pipes are confined to the carriage of slop-waters and bath-wastes, while 6-inch connections are made to water-closets.

Mr. Davis. *Gradients.*—1 in 40 for 4-inch pipes, and 1 in 60 for 6-inch pipes, are the flattest gradients allowed, except in a few rare cases where modifications are inevitable.

Jointing.—In all ordinary cases the pipes are carefully bedded on the barrel, and the joints are made with cement-mortar composed of 1 part of cement to 2 parts of sand. In water-charged ground, iron pipes with gasket and lead joints, or stoneware pipes with gasket and full cement joints on concrete foundations, are used.

Drains beneath Buildings.—Where the laying of a sewer beneath a building is unavoidable, the pipes must be carefully embedded in, and covered and surrounded with, good concrete at least 6 inches thick all round.

Soil-Pipes.—These are generally of lead, in which case they must not be less than 4 inches in diameter, and of 7-lb. lead; or, if cast-iron is used, it must not be less than $\frac{1}{4}$ inch thick. Soil-pipes must be fixed to the outside of a building, and be continued upwards, without decrease of diameter, to such a height as to afford a safe outlet for sewer-air.

Disconnector-Traps.—These are placed, where practicable, within the boundaries of the property, but as far from the house and as near to the sewer as possible.

Ventilation.—A ventilating-pipe to serve as a fresh-air induct is carried from the disconnector-trap, and an upcast shaft with cowl, usually attached to a wall of the house, is fixed at or near the head of the connection.

Mr. Naylor. Mr. NAYLOR, in reply to the Correspondence, remarked that he could easily understand that any resort to drastic measures, likely to shut out those well-known methods in the cause of which Colonel Jones had always been such an ardent advocate, would hardly meet with that gentleman's approval. But he felt sure that if Colonel Jones would examine the Paper closely he would at once admit that it did not for a moment preclude the possibility of recovering useful products from trades waste before it was discharged into town sewers. Indeed it did not entertain at all the idea of delivery into sewers after treatment. And if it could be shown in any instance that the bacterial treatment set forth in the Paper was likely to deprive the sewers of any benefit, or—what he surmised was rather Colonel Jones's fear—sewage-farms of any manurial wealth, then the question would need to be decided between the trader and the municipality on that ground. But, up to the present, local authorities did not appear to be anxious about it, and the traders themselves had a fairly accurate idea as to what it was worth, and bemoaned not the loss of it. He submitted that Mr. Scudder's criticism, applied to a new venture, was inclined to be rather captious. To have declared boldly that the Paper was open to severe criticism from a chemical and bacteriological point of view, and then to have retired saying that it would not be desirable before a society of

engineers to enter into a purely scientific discussion, and to have Mr. Naylor. suggested vaguely the existence of "numerous investigations which have been made into the chemical and physiological relations, and the modifying external factors of temperature and acidity concerned in the action of the diastatic ferment of bacteria in the transformation of starch," amounted to having stated that certain contradictory evidence could be produced, but that, owing to its being purely scientific, a society of engineers would hardly be the place for it. At the same time, if, in the sentence quoted, Mr. Scudder referred to numerous investigations into (1) the conversion of starch by diastase, and the bacterial fermentation or disintegration of starch and allied compounds; (2) the extent to which these processes were affected by (*a*) external conditions of temperature, and (*b*) contact conditions of acidity; then Mr. Naylor could only say that the experiments set forth in the Paper had been conducted with those investigations fully in mind, and with careful note of many other conditions, both of a purely scientific and of a practical character. One basis of the Paper was the statement that starchy products such as beer, potale, brewery-waste, colour-printers' thickenings, and wheat-washings, became sour when left exposed to the atmosphere. If that statement was not "scientific" it was much to be regretted, because it was a hard fact. The other basis was the accepted law of the struggle for existence throughout the whole of nature, and the survival of the fittest. All that he had attempted in the Paper was to record certain experiments made with the object of ascertaining which of two not thoroughly differentiated species of life proved to be the fittest in a struggle brought about artificially. The experiment with starch-paste was the first of these experiments, and it was so simple that it could be made by any one with little trouble, and the conclusion could be verified, namely, that freshly-made starch-paste, well mixed with putrid sewage-sludge and left as in a septic tank unexposed to the atmosphere, was decomposed with only a slight formation of acid, the resulting mass being amenable to bacterial filtration. The sludge, however, should be ordinary sludge; and the solids therein should be in a state of fine division. He accepted Mr. Scudder's as a bona-fide attempt to make a parallel experiment in which discordant results were obtained, and the matter was one that might be left there. Whether the analytical figures in Table I. did or did not indicate appropriately the changes which had been brought about in the liquid was beside the question. The real question was—

Mr. Naylor. Did they indicate appropriately whether or not certain anticipated changes had been brought about in the liquid? The whole procedure was a trial of a preconceived idea, correct or otherwise, not an investigation into a theory; and in any case, throughout the history of engineering exploits, practical workers had run right in the teeth of theorists, leaving them afterwards to explain at leisure by investigation how it was that, after all, well-known natural laws had not been contravened. Mr. Scudder's doubts concerning minor details—the quantity of sludge required, the volume of sludge produced, quantity of suspended solids in final filtrate (regardless of their character or ease of interception), reduction of alkalinity, high figure for nitric nitrogen—were all thrust prematurely into prominence beside the main issue, compared with which they were about as important as was the pattern of its oil-cup to the action of the Diesel engine, or the external appearance of its castings to the running of the Parsons turbine. The evidence adduced concerning the difficulty of persuading the firm of Messrs. Peel, Tootal & Co. to do anything at all in the matter of preventing river-pollution, showed, if anything, that any successes obtained there under such awkward circumstances were indicative of greater success to be attained elsewhere. He had no power over the action of the directors of the firm, and but little in the question of satisfactory maintenance or of substantial construction; and though the works, as shown accurately in *Fig. 1*, might bear the impress of a first installation, the results were always eminently satisfactory with an ordinary amount of attention. With regard to progress made elsewhere, at the present moment several important and substantial installations were being actively proceeded with in Lancashire, Yorkshire, and the West of England, and in the course of another session of the Institution some member might be found to present an account of the success or failure of these. Mr. Tatton's views, though much broader, were somewhat restricted to the particular instances of the Paper. Truly, for a bleach- or print-works with 500,000 gallons to 1,000,000 gallons of waste liquors per day to provide tank-capacity for three days' flow was an alarming prospect. But of this quantity nearly 75 per cent. was quite amenable to straightforward settlement or mechanical filtration, and would yield from such treatment an effluent good enough to come within the four corners of any Rivers Pollution Act. In such cases, for the remainder, or in cases of small works like Messrs. Peel, Tootal and Company's, or breweries or distilleries, an "anti-souring" tank with

two days' or three days' capacity might well be provided. In short, the method was suggested as one for the satisfactory treatment of liquors containing starchy products, which up to the present had presented almost insurmountable difficulty. If these liquors formed only a small part of the gross discharge then local circumstances should decide the particular method of separation and subsequent procedure. Mr. Naylor.

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4 February, 1902.

CHARLES HAWKSLEY, President,
in the Chair.

It was announced that the Associate Members hereunder mentioned had been transferred to the class of

Members.

Charles Sydney Vesey Brown.
William Bernard MacCabe.
Richard Watkins Richards.
William Spinks.

And that the following Candidates had been admitted as

Students.

Arthur Campbell Clifford.
Arthur Melvill Close.
Charles Harold Cottew.
Leopold Daniel Coueslant.
Leonard George Crawford.
Frank Harvey Farmer.
William Ernest Gardner.
James Francis Gill, B.Sc. (*Victoria.*)
George Howard Greenwell.
John Mackintosh Hogg.
Thomas John Ransom Kiernan.
James Niven Laing.
René Edmund Lehuraux.
Ronald Charles Scott Murray, B.A. (*Cantab.*)
Edward Thomas Newton-Clare.
Hamish Norman Ogston.
Thomas Clement Ormiston-Chant.
Louis François de Peyrecave.
Kashi Ram Puri.
Oscar Branch Rattenbury.
Alexander Richardson.
Francis Bertram Robinson.
John Kercheval Sidebottom.
Ivan James Thatcher.
George Walter Tripp.
Alphonse Wood, Jun.

The Candidates balloted for and duly elected were: as

Members.

Arthur William Henry Casson.
Henry Disney Ellis.
John James Impett.
James Norman Digues la Touche.
Francis Thomas Rednall.
George Fillmore Swain.

Associate Members.

EDWARD VINCENT CLARK, B.Sc. (*Adelaide*), Stud. Inst. C.E.
RONESCHANDRA DAS.
HARRY DUNCAN DORMOR, Stud. Inst. C.E.
ROBERT WHITEHEAD HAMMOND, Stud. Inst. C.E.
FREDERICK JAMES JONES.
CHARLES BELL MCRITCHIE, Stud. Inst. C.E.
FREDERICK ARTHUR MOLONY.
JAMES MOUNTIFIELD.
TOM OSBERN MULLINGS.
WILLIAM HARDCASTLE NEILSON, B.A.I. (*Dubl.*)
ARTHUR CECIL HUNTER PALMER.
ARCHIBALD CAMPBELL RETTIE.
LESLIE ROSEVEARE, Stud. Inst. C.E.
TOJIRO SANO.
REGINALD SAUL SOLOMON, Stud. Inst. C.E.
HAROLD SPENCER THRELFALL, M.Sc. (*Victoria*.)
FREDERICK JOHN TYLEY.
ROBERT WILLIAM VAWDREY, B.A. (*Cantab.*), Stud. Inst. C.E.
JUNNOSUKE YAMAGUCHI.

An Associate.

JAMES FORSYTH THALLON, *Lieut.-Colonel Australian Defence Force.*

The Discussion upon the Papers on "The Sewerage Systems of Sydney, N.S.W., and its Suburbs," by Joseph Davis, M. Inst. C.E., and "The Bacterial Treatment of Trades Waste," by William Naylor, Assoc. M. Inst. C.E., was continued and concluded.

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 3282.*)

"Railway Surveying on the Pipli Ghat."

By Gordon Risley Hearn, *Captain* R.E., Assoc. Inst. C.E.

In the year 1898 instructions were issued by the Government of India for the survey of a line of railway between Bara, on a branch of the Indian Midland Railway, and Marwar Junction on the Rajputana-Malwa State Railway, with a branch or alternative line to Ajmere. The line between Bara and Marwar Junction will constitute a link in a chain of railways stretching from Karachi to Calcutta, Fig. 1, Plate 5. Unfortunately the railways to be connected are not of the same gauge, but this may be rectified at some future date. Estimates were to be prepared for both standard (5 feet 6 inches) and metre gauges. The "battle of the gauges" still continues in India, and while certain Chambers of Commerce favour the standard gauge for such a line, there are some conflicting interests in the scale on the other side.

Between Lambia and Marwar Junction the line had to cross the Aravalli range, which is the extension to the north of the Western Ghats of India, crossed by the Great Indian Peninsula Railway at the Thul and Bhor Ghats. In the descent to the plains near Pipli extremely difficult work was encountered. A ruling gradient of 1 in 55 was suggested, and after reconnaissance a traverse was run and the line was projected on paper; this gradient, however, involved a great deal of curvature and heavy work, and it was considered that possibly a gradient of 1 in 40 might involve less work and prove a cheaper line with less curvature—a very desirable point if the gauge should at some future date be widened to standard gauge. In the season 1899-1900 the Author was placed in charge of a party to re-survey the Ghat on this basis and to locate the line. As a result a more favourable alignment was obtained, but it was found that the actual cost of the shorter line was greater, and that more tunnelling was involved than had appeared

necessary with the lower gradient. This enhanced cost, however, was due to several factors and especially to the width of formation adopted, which was suitable to the standard gauge, though not of full width. It is also practically certain that if the previous line had ever been located on the ground, and a true estimate had been prepared with better information, there would have been a balance in favour of the steeper gradient and better line.

The ruling gradient of this survey (1 in 40) was compensated at a rate of 0·05 per cent. per degree for all curves of over 3° or 1,910 feet radius. The sharpest curve is 10° or 573 feet radius, but there is only one of these, located to avoid a rather long tunnel on the curve. Otherwise there is no curve of less than 716 feet radius, and such curves represent 25 per cent. of the total length of line. This may seem too sharp for a standard-gauge line, but the speed would be necessarily slow, and in all station-yards in India locomotives and vehicles pass over 1-in-8½ crossings, involving a radius of 800 feet. It is probable that special locomotives would be employed on this section in any case, and such curves present no difficulty to four-wheeled stock of the ordinary type. The curves in this section represent only 39·37 per cent. of the total length of the line, as compared with 63·17 per cent. on the first survey.

Nature of the Country.—The traveller from the deserts of Marwar (Maroo-war, or the region of death) to the fertile plateau of Mewar or Udaipur, traverses a practically flat country for a distance of about 16 miles after he leaves Marwar Junction. He then has to face a stiff climb of nearly 1,000 feet, till he reaches the summit of the pass, to find a plateau falling gently towards the east. The path is very steep and, though nominally fit for camels, can really only be negotiated by buffaloes and bullocks, which were largely used in the old days to carry up burdens of salt and merchandise from Marwar to Central India. The section of the scarp of the Aravalli range at this point resembles the back of a huge masonry dam, almost precipitous at the top and gradually sloping away to the base. Outlying spurs are few and far between, and fall steeply, and were it not for the huge mass of Mount Goram rising 2,000 feet above the plain and joined to the main scarp by a high saddle some 4 miles north of Pipli, the only way to descend would be to slant along the scarp till the plain was reached, thus taking the line 8 miles to the north; but by means of this saddle a turn can be made and the line brought back along the slopes of Goram.

General Line Adopted.—In the instructions for the survey in 1898

the road over the Pipli pass was cited as a possible route, but this is a mere track up the scarp, and is much too steep. Close to the village of Pipli, which is about 1½ mile to the east of, and about 50 feet lower than, the edge of the scarp, a valley starts running west, and full advantage was taken of this fortunate feature. This valley has to the eye a gentle fall, but in reality, owing to occasional sheer drops, the average fall is not less than 1 in 20, and consequently the line on a 1 in 40 gradient soon mounts high on the northern hillside. On approaching the scarp this valley turns south-west, and eventually falls down a sheer precipice, which the bullock track skirts. It was therefore necessary to cross a saddle into a smaller valley which emerges on the scarp a little farther north. A sharp turn on to the main scarp was avoided by crossing and re-crossing the valley. After this the scarp was contoured for 3 miles, until the turn on to the lower slopes of Mount Goram gave easier work. A feature of this next portion, however, was the frequent occurrence of long spurs with knolls at short intervals. The valleys between being deep and rather steep, to keep on the outside of these knolls in light cutting would have necessitated viaducts in the valleys, while to keep on the inside with moderate banks involved deep cutting. It was impossible, moreover, to resign any of the fall and equalise matters, for this would have led to great expense lower down. Another feature of these slopes was the thick jungle, and had it not been for the method adopted, several trials, causing much delay, would have been necessary before the line was properly located. After running for 3½ miles on Mount Goram the last saddle was reached near Phulad. Crossing this, open country was reached, but steep gradients were still necessary almost until the line was joined into the old line located in 1898–99. Having decided on the best general line, the next operation was to run a trial line on the "grade contour" through points fixed by an Abney level set to the probable average gradient (1 in 44 for a maximum gradient of 1 in 40). The chaining was done only roughly, and bearings were taken by compass.

Preliminary Survey.—When the trial line had proved the feasibility of the route, a preliminary survey was commenced. In the first survey of this ghat one executive engineer, one assistant engineer, and three subordinates were fully employed. To each man was allotted one of the following duties, the executive engineer assuming the general direction.

Theodolite Traverse.—This followed more or less closely the average "grade contour," the chief aim being to map the ground

adequately without throwing too much work on the rest of the staff. The traverse was made to approximate closely to the final line, so that—

(*a*) Shorter cross-sections sufficed;
(*b*) Subsidiary lines were seldom required;
(*c*) The final line could be set off from the preliminary line; and
(*d*) Less jungle clearance was afterwards necessary.

In order to make the work of the chainmen and leveller less arduous, having regard to the nature of the country, short lines were taken. That accurate work can be done in this way is illustrated by that part of the survey shown in Fig. 2, Plate 5. It will be seen that three tie-lines were run to map the ground for the turn, and these all scaled correctly on the plan. When locating, one tangent was re-measured because it did not agree with the scaled length, and the plan was found to be correct.

Chaining.—On the steep and broken ground of this ghat the chaining proved most trying work, and the Author would in future invariably use a tacheometer. If this be combined with the theodolite it does not throw much extra work on the observer. The man superintending the chaining was also responsible for driving pegs at all points at which cross-sections were to be taken. These were usually at the summits of spurs and the bottoms of valleys, and if these were large more cross-sections were taken, to show how the contours ran. Pegs were also driven where the slopes along the centre-line altered, as spurs are usually flatter on the top than on the side slopes. Cross-sections were not necessarily taken from such pegs, but they had to be levelled over. On each peg was written the chainage from the last traverse station, the 100-foot chain being used, as is the universal practice in India. The Author recommends that the executive engineer should himself superintend the placing of these pegs, as he knows best how he wishes the ground mapped. A man will be thus set free for check-levelling—a very necessary operation on such hillsides.

Cross Sections.—These were taken with an Abney level, and were entered in the form given in Appendix I. Sometimes, and especially in valleys, the bearing of the cross-section altered, as at (*a*) and (*b*) at 298 feet from station No. 14 (Appendix I). The slope, whether + or −, was read on a vane set to the observer's eye. When the slope altered it was set down below the first slope. The length of cross-section measured on the slope was afterwards reduced to the horizontal. This was necessary where the bearing of the cross-section altered. If there was one general slope for over 100 feet it was entered as "16° forward." The

length of cross-section taken varied with the nature of the slopes, being longer on the flatter slopes, but always over 50 feet on each side of the centre-line.

Levels.—These were taken on all traverse-stations and intermediate pegs, a list of which was given to the leveller. In the first half of the line, as it was usually the case that between two stations 50 feet to 100 feet of fall and rise had to be levelled, a distance of 800 feet to 1,000 feet was considered a good day's work, and even this was not always attained, as the work lay far from camp, necessitating a climb of 800 feet before commencing operations. The levels were checked on the traverse-stations only, and the through level corrected, the error being thrown into the intermediate work. With contours at vertical intervals of 10 feet on slopes such as obtained, an error of even 1 foot may be neglected, but great care was taken to keep the through level accurate.

Plotting the Traverse.—The observed information having been collected and tabulated nightly, the work of plotting was taken in hand. At first the slowness of the levelling enabled the theodolite observer to remain in camp every third day or so, and by taking advantage of Sundays, on which field-work was suspended, the plotting was kept up to the work; but in the lower portion the jungle was heavy, and the clearing of the traverse-lines occupied much time, while, the ground being easier, progress with the level and chain was quicker. It was therefore found necessary to suspend the field-work on one day in the week in order to plot. The operation of plotting was carried out as follows:—

(1) The traverse was laid down by the Gale system of latitudes and departures to a scale of 200 feet to an inch.

(2) The intermediate pegs were marked.

(3) The cross-sections were laid off (Appendix I).

(4) The reduced lengths (Appendix I) were marked off, and the slopes (+ or −) were entered on the plan.

(5) The reduced levels of all stations and pegs were entered.

The condition of the work at this stage (between stations 13 and 14) is shown in Fig. 3, Plate 5.

The next operation was contouring, and this was done by means of scales showing the horizontal distance due to a 10-foot vertical interval on the various slopes 3°, 4°, 5° to 20°, then 22°, 24° to 30°, and 35°, 40°, and 45°; the differences being so small for the intermediate slopes above 35° that they can hardly be scaled, the nearest scale was taken. For the same reason slopes were read to the nearest degree on the Abney level. The various operations

culminating in the contoured plan are illustrated in Fig. 3, Plate 5. At every 50 feet vertically a thick contour was drawn, and this was repeatedly numbered in order to save time in projecting the paper location, when it is frequently necessary to know the level of any contour. The Author would suggest that the work of contouring is better done on a plane-table in the field, for although this may take rather more time, the result will be more accurate on steep slopes. On the easier slopes the method described gives the best results.

Plotting the Paper Location.—On the careful location of the line on paper depend the reduction of the work of subsequent location on the ground and the ultimate cost of the line. Alterations may, and indeed must, sometimes be made on the ground when locating, but the fewer of these the better, especially when the time limit is short owing to the advent of the hot weather. During construction also the line may be altered, but it is naturally desirable to get the best line located. The greatest care is therefore necessary, and if it be found that the located line is departing rather far from the traverse, it is better to run subsidiary lines at once than to trust to finding similar slopes lower down the hillside. It being known at what level the summit or controlling point would be reached, a pair of compasses was set to a horizontal distance on the scale due to a fall of 5 feet on an average gradient of, say, 1 in 42. These distances were then set off along the probable alignment, and were numbered at every 10 feet, a cross being made where the "grade contour" cut the ground contour of the same value, Fig. 2, Plate 5. It may be noted that one defect of the contoured plan is the absence of information as to the actual cross-section, and although it can be seen that the side slope is a steep one, yet it cannot be determined at sight to what height the bank can be taken with a certainty of its being able to stand without going very far down the hillside. The worst banks can be cross-sectioned from the plan, but in the case of this ghat there were so many cross valleys that this would have taken much time. Moreover, the worst place might not, and frequently did not, occur in the centre of the valley. On very steep hillsides (over 30°), of which there was a considerable length, no bank was possible, and where slopes were easier cuttings were avoided, as being much more expensive than banks. Should a straight line through these points be inexpedient, it may be possible to reduce work by curvature, and it may, of course, be evident from the first that a curve is necessary. A very speedy method employed to ascertain the most suitable curve was by means of an unexposed and fixed

photographic plate having arcs of curves of various radii drawn on the gelatine side. By moving the plate over the plan it could at once be seen which curve suited and how it would best lie. On this ghat it was constantly found that the line was tied by difficult places, which increased the work on both sides where otherwise it would have been light.

Description of the Line as Located.—When located on the ground the line agreed very well with the paper location except in one or two places, where it was found necessary to keep well into the hill-side on account of the steep side-slope. Alterations were also made towards the end, owing to modifications of the line, which gave a greater fall. Owing to the severe famine the portions of the line above and below the ghat section had been taken in hand as famine-relief works, so the point of starting at the top (187 miles from Bara) was practically fixed. The saddle leading into the smaller valley above mentioned was another controlling point, at 188 miles, and the alignment and grading over this mile were arranged so as to give about 40 feet of cutting through the saddle. The hillsides were steep, and unfortunately part of this section was located in too high a bank, as the effect of the side slopes was hardly realized at the commencement of the work, and this required some realignment. At 187·6 miles no bank was possible, owing to a sheer fall about 140 feet from the centre-line, and a masonry viaduct was adopted. Then followed a large cross valley into which it was not possible to curve with an 8° curve; the length of bank was reduced, however, by taking advantage of a projecting spur. Beyond the saddle at 188 miles the valley was followed which gave into the main scarp; by crossing this, easy work was obtained on the south side until it was recrossed on to the main scarp. Keeping on the north side would have involved heavy banks and a sharp turn in a tunnel. Up to this point the work though heavy is not very difficult; but there now ensued ½ mile of sheer rock and precipice and the line had to be kept in cutting as much as possible, with arches or retaining-walls where scars were crossed. At 188¾ miles occurs a sheer precipice over 100 feet in depth; a narrow ledge was found, along which the line could be run, but the level of the line will be 50 feet lower than this ledge, and a gallery will probably have to be driven at least part of the way to avoid danger from falling rocks. Then comes one of the worst features of the ghat, a regular "scoop" out of the hillside, with two waterfalls. This required a great deal of consideration, and eventually it was decided to tunnel through each of the adjacent

spurs, and to keep close in on side cutting. The waterfalls were to be dammed and the overflows led in one case over, and in the other under the line, in channels cut in the rock. On emerging from the tunnel after the "scoop" another valley is crossed at a very oblique angle; the bank will be formed from tunnel spoil and the water diverted through a high-level opening. For the next $\frac{3}{4}$ mile, while no great difficulty is encountered, the steep slopes prohibit banks of any height, and the line has to be run mainly in cutting or tunnel. At 189·9 miles there is an extraordinary dip in the strata, which stand at an angle of 60° to the horizontal. Any cutting is out of the question, as the whole would fall in; a tunnel has therefore been adopted. It may be mentioned that the tunnels, as far as can be seen, will require no lining, as the rocks are trap, basalt, gneiss and granite of various forms. Over this section the spurs and valleys are very frequent, and there is not room to curve and save work, Fig. 4, Plate 5. After $190\frac{1}{4}$ miles the hillsides become less steep, but there are several long and rather wide spurs jutting out, which render it necessary to make full use of curvature. Even then, cuttings and banks attain a height of about 50 feet; but it is impossible to reduce this unless the tangents between reverse curves be shortened, and 200 feet of tangent should be allowed if possible.

At $190\frac{3}{4}$ miles there is a very steep valley called the Jogmundi Nala, succeeded by a high and broad spur with another difficult valley on the other side. Matters were also complicated by the fact that it now became necessary to turn in the main valley, which, though apparently broad, is still too narrow to get in a half-circle of an 8° curve without heavy tunnelling, owing to the broad spur jutting out on the further side. Three alternatives were considered, including the location of a reversing-station, but eventually the line was located as shown in Fig. 2, Plate 5, giving a better and lower crossing of the main valley, greater distance and fall, and a shorter viaduct, at the expense, however, of locating a 10° curve, rather sharp for a standard-gauge line, but the only one on this section. The length of viaduct in the main valley is 430 feet, with a maximum height of 95 feet. The Jogmundi viaduct is also a long one, and two tunnels, one of 1,000 feet and the other of 400 feet in length, are necessary, but on the whole this seemed to be the best solution of the difficulty. The section of the line at this point is shown in Fig. 4, Plate 5.

Shortly after the turn, a crossing-station was located; the ther heavy, yet having regard to the distance from

Pipli and the good sites for staff-quarters, etc., no other place could be found with equal advantages. A length of 1,600 feet of level has been provided, of which 2 chains will be utilized to merge the gradient into the level, 4 chains will be necessary for crossings and turnouts, and the remaining 10 chains should be ample to cross the short trains running on the ghat section.

After leaving the station a very broad spur juts out from Mount Goram, but it is possible to curve round this with easy work on the face. After this, a succession of long wooded spurs with deep valleys between extends for ¾ mile. A short unlined tunnel through one of these will prove a saving, but the others necessitate long cuttings through the saddles; the spoil, however, will go to bank in the valleys. As the line descends, the spurs become very long and the valleys between broad. A good deal of consideration was necessary in deciding what to do in a valley at 194½ miles. Advantage was taken of a long spur to descend as far as possible, and the valley was crossed low down on a high bank; crossing higher up would have involved a tunnel and a viaduct, which would have been far more expensive. The estimated cost of this bank, however, is as much as two-thirds of a lakh of rupees. The rest of the line presented little difficulty, being mostly on low bank, though heavy gradients had still to be employed to suit the fall of the country.

Location of the Line.—After a hard day's work in the actual location of this line on the ground, involving a ride from camp of 3 miles, a climb of 500 feet before commencing work, and 8 hours or more spent in climbing about the hillsides, perhaps one tangent had been laid out and chained, and the centre-line had not been advanced one foot. In nearly every case platforms had to be built round the pegs. All the ranging-rods were fitted with plumb-bobs to ensure that they were held vertically, for seldom indeed could the bottom be seen from the instrument. The theodolite work, however, which was done by the Author, was easy compared with the labour of chaining. The line was staked at every 50 feet, but the chain could very rarely be held level for that distance. There were three chainmen, one of whom only pulled the chain forward when necessary. The fore and back chainmen had long bamboos, by which they might raise the chain to clear rocks and obstacles; these rods had to be held vertical and the native of India has not a "straight eye." The chain being held to a regular slope and the rods vertical, that slope was read with an Abney level, and a reference to a Table showed how many feet on the slope

corresponded to 50 feet horizontally. The forward chainman was moved to that distance, when perhaps the slope had to be read again; but eventually the correct distance was found, the line was given from the instrument, and the peg was driven after about ¼ hour's work. The location of 40,253 feet of centre-line on the ghat occupied 46 working-days; out of this 18,414 feet was on the curve and an additional 20,547 feet had to be measured in tangents. For every foot of located line 1½ foot had to be chained. It may be objected that the use of the chain is a mistake on such ground, but it cannot be dispensed with entirely; for, although a tacheometer can be used on the straight, a chain, preferably a steel band, must be nsed on the curve. The amount of calculation also with the usual type of tacheometer would be enormous. In laying out curves with the theodolite, the instrument had to be moved at least three times for a curve of any considerable length. It was deemed unnecessary for survey purposes to go over a curve repeatedly in order to get it within a foot of the calculated length, a margin of 1 per cent. being allowed. The greatest care was taken with the tangent distances, and the through chainage was taken up as calculated. In chaining the tangents to the curves at the turn, Fig. 2, Plate 5, the length across the valley was 1,393 feet, and the heights at each end of the double tangent were 320 feet and 170 feet above the bottom of the valley. In one case tangents of 1,022 feet each had to be measured, the length of the curve being only 1,375 feet. The labour of calculation for tangent distances and length of curve was much reduced by an excellent little book of curve Tables by Mr. F. G. B. Fox, M. Inst. C.E., which was found invaluable in view of the considerable number of curves. While locating, notes of probable slope of cuttings, nature of rock, etc., were entered in the field-book for use in the office. Trial pits also were sunk.

Cross-sections were taken with an Abney level at every 50-foot peg and at right angles to the line; they were also taken at the tops of spurs and in the bottoms of the valleys, in order to get the greatest area of each bank or cutting. When plotted, the section of bank or cutting was drawn in from templates, and the area was measured by means of a planimeter; these areas were then averaged, and the mean area was multiplied by the length of the earthwork to give the cubic content. The cross-sections were also of great use in investigating possible realignments.

The centre-line was levelled over and frequent bench-marks were put down, Fig. 4, Plate 5. These bench-marks were then check-levelled by another man, and few errors were found. As an

instance of the labour involved, it may be mentioned that in 4,340 feet the leveller had to rise and fall 1,424 feet, necessitating setting up the instrument 117 times. This was exceptional, but a study of the section will show the nature of the work generally, Fig. 4, Plate 5.

The longitudinal section and more important cross-sections were plotted daily, and, with these to refer to, the line was walked over and the waterways were settled. It was, however, quite impossible to take all the information necessary to design each bridge, as a whole season's work might well have been devoted to this alone; the amount of waterway shown is probably excessive. Nearly all of the larger bridges have had to be put in on account of the steep side slope prohibiting banks, or because a viaduct was necessary. For the smaller culverts the principle of putting them at a higher level, and thus saving length, was adopted.

The drawings were made in the office after the usual type, with, however, one useful innovation. It will be understood that the section of the line gives but a rough idea of the amount of work, unless read in the light of the cross-sections, and as the examination of two sets of drawings at once is inconvenient, the side widths of banks and cuttings, as shown by the cross-sections, were plotted on the plans, and coloured with a flat wash, green for bank and red for cutting. It can therefore be seen at a glance where the work is heavy or light.

The estimates for the large bridges were prepared from skeleton and detail drawings; for small culverts, the Tables of Mr. E. H. Stone, M. Inst. C.E., were used, the length being measured from the cross-sections. Tunnels were estimated for at rates deduced from working on the Simplon and Mushkaf-Bolan tunnels. Earthwork quantities were obtained from the cross-sections, as already mentioned.

The estimated cost of each mile, under the several heads of work, is given in Appendix II; the most expensive mile, however, would cost about 5 lakhs of rupees, or £34,000, in works alone. The cost of the ghat section, when fully equipped, is estimated at Rs.27,68,570 on the standard gauge, or an average rate of Rs.2,61,131 (£17,408) per mile.

The Paper is accompanied by nine photographs and the following Appendixes; and by four drawings, from which Plate 5 has been prepared.

[APPENDIXES.

APPENDIXES.

APPENDIX I.

Cross Sections (Left-Hand Side).

Traverse Chainage.	Traverse Bearing.	Cross-Section Bearing.	Difference of Bearing.	Abney Level Reading.	Length.	Reduced Length.	Remarks.
	° ′	°	°	°	Feet.	Feet.	
Station No. 13 Ch. 587	252 50	181	72	−18 − 7	100 72	94 72	
128	..	155	98	− 1 + 1	107 90	107 90	
290	..	163	90	− 6 + 2	26 66 (*a*)	26 66	
a i	..	183	70	− 8	100	99	
a ii	..	131	122	−10	105	103	
400	..	165	88	− 8 + 9 − 3 −13	11 70 38 60	11 69 38 58	
456	..	190	63	+14	86	83	
678	..	112	141	+12	100	97	
ii	..	203	50	−10	126	123	
Station No. 14 Ch. 722	223 30	195	28½	−11	103	101	
200	..	140	83½	− 7 −17	40 80 and forward	40 ..	
298	..	122	101½	−11	50 (*a*)	49	
a	..	140	83½	−10	25 (*b*)	25	
b	..	125	98½	−13	103	100	
Station No. 15 Ch. 387	298 5	236	62	− 2	77 (*a*)	77	
a	..	221	77	− 5	150	150	
S. 15 *ii*	..	144	154	+13	100 (*a*)	97	
a i	..	..	..	+ 4	50	50	
a ii	..	57	241	−16	65	62	and forward to Nala.

APPENDIX II.

Cost of Works (Standard Gauge).

Mile.	Earthwork.	Tunnels.	Viaducts.	Minor Waterways.	Total.
	Rupees.	Rupees.	Rupees.	Rupees.	Rupees.
187	76,139	..	12,747	18,254	1,07,140
188	59,535	1,68,904	11,217	12,560	2,52,216
189	88,324	2,12,920	12,418	16,601	3,30,263
190	92,106	1,74,214	1,23,132	25,041	4,52,493
191	45,796	1,81,301	1,56,446	18,204	4,01,749
192	92,809	24,762	..	42,099	1,59,670
193	39,204	..	..	11,423	50,627
194	98,217	..	..	62,236	1,60,453
195	2,951	..	..	5,109	8,060
196	5,098	..	13,848	319	19,265

	Rupees.
Average cost (including contingencies) per mile	2,03,903
Estimated final cost (including equipment) per mile . .	2,61,131

(*Paper No. 3305.*)

"Repairs to and Maintenance of the Pretoria Eastern Railway."

By George Bransby Williams, Assoc. M. Inst. C.E.

In the following Paper is presented a description of some of the work of the engineering department of the Imperial Military Railways during the first few months after the occupation of the Transvaal by the British troops. The work described is chiefly that of the repair and maintenance of the line east of Pretoria, a considerable portion of which was carried out under the supervision of the Author, who held a staff appointment as engineer on the railway during the period mentioned.

General Description of the Line.—The Pretoria Eastern Railway connects Pretoria with the Portuguese border, where it forms a junction with the Lorenzo Marques Railway, Fig. 1, Plate 6. It is the shortest route between the Transvaal capital and the sea. The total length of the line is nearly 300 miles. The first portion, from Pretoria to Waterval Boven (160 miles), is constructed on the high veldt, at altitudes varying between 4,500 feet above sea-level at Pretoria and 6,000 feet at Belfast, the summit of the line, Fig. 2, Plate 6. This part of the railway, being constructed on an extensive undulating plateau, is almost a surface-line, with long lengths of straight line and flat curves. The gradients are long, and in places steep, the ruling gradient being 1 in 50. Between Waterval Boven and the Portuguese frontier the railway runs through a rocky valley, at places narrowing almost to a gorge, which at about 30 miles from the border widens out into a flat plain, thickly covered with trees and bushes. On this section of the line the works are much heavier than on the high veldt, and the railway runs through cuttings and over embankments of considerable height as it winds along the hill-sides, following the bends of the Elands and Krokodil rivers, keeping on the south side throughout the whole distance. The curves are sharp, a consider-

able number being about 7½ chains radius (150 metres). The gradients are not exceptionally steep, the line falling gradually the whole way until at Komati Poort it is only a few hundred feet above the sea. Between Waterval Boven and Waterval Onder there is a rack-railway, 2 miles in length, worked on a combined rack and adhesion system. Most of it is at a gradient of 1 in 20. Four special cog-engines are kept at Waterval Boven, and one is attached to the rear of every up-train, and to the front of every down-train between that place and Waterval Onder. There is a branch line from Kaapmuiden to Barberton, a small gold-mining town of some 2,000 or 3,000 inhabitants. The only place on the main line that can be dignified by the name of a town is Middelburg, 90 miles from Pretoria, which has about 1,500 inhabitants. Waterval Boven, a village prettily situated amongst fine mountainous scenery, is the railway headquarters for the line, and is composed chiefly of workshops, offices, and houses built for the railway staff. There are also locomotive-sheds and workshops, maintenance-shops and stores of railway material. The railway runs through coal districts at Balmoral and Belfast, where the coal is being worked to some extent at four or five collieries.

Repairs to the Line.—For some time after the capture of Pretoria, the furthest point east of that place occupied by British troops was Pienaars-Poort, 15 miles from Pretoria, on the Eastern Railway. This was the extent of line worked by the Imperial Military Railways until the end of July, when a general advance took place, which opened up the line as far as Wonderfontein, 30 miles beyond Middelburg, and 120 miles from Pretoria. At the end of August a further advance was made, which ended in the capture of Komati Poort on the 24th September, 1900. The Boers, as they retired, did considerable damage to the line. In the following Table (page 278) is given a list of the bridges destroyed, and the damage done in each case.

The breaks were repaired with great expedition by the railhead construction party, which consisted of about sixty Royal Engineers, with several hundred natives, divided into gangs of thirty, under white gangers. At Bronkhurstspruit, Wilge River and Kaapmuiden deviations were constructed, 400 yards to 600 yards in length, and at Avoca there was a deviation of nearly a mile in length. The ruling gradient on these deviations was 1 in 30. At Wilge River, the river having to be crossed in one span, trussed beams 50 feet in length were used. These were inverted queen-post trusses, the upper boom and vertical struts being baulks, 16 inches by 16 inches in cross-section, and the ties four round-iron rods 1½ inch in

diameter, bolted to anchor-plates at each end of the upper boom. Four of these trusses were laid side by side on crib-piers. On the other deviations temporary bridges were built, on trestles,

Name of Bridge.	Miles.	Description.	Damage done.
(1) *Main Line.*			
Van der Merwe . . .	273	1 girder, 33 feet span	Girder and east abutment destroyed.
Bronkhurstspruit . . .	255	3 " 66 " " 1 " 33 " "	First and third piers entirely destroyed. Both abutments and centre pier partly destroyed. 66-foot girders badly damaged. 33-foot girder destroyed.
	251 250	1 " 16 " " 1 " 16 " "	Both abutments and girders destroyed.
Wilge River	246	1 " 98 " " 2 " 33 " "	All masonry and both 33-foot girders wrecked. 98-foot girder back broken, ends resting on each bank of the river.
Waterval Onder . . .	127	1 " 66 " "	East abutment destroyed, girder much damaged.
Gudwan River	106	2 " 66 " "	6 feet of masonry of centre pier blown down. West end of eastern girder damaged. Western girder much damaged.
	53	2 " 49 " "	Centre pier destroyed, both girders much damaged.
Kaapmuiden	47	3 " 100 " "	12 feet of eastern pier destroyed. Centre girder wrecked. Eastern girder much damaged at west end.
	26	1 " 33 " "	East abutment damaged and girder destroyed.
	17	1 " 49 " "	Both abutments damaged and girder destroyed.
(2) *Barberton Branch Line.*			
Avoca	..	4 " 102 " "	Three piers somewhat damaged. East ends of three girders blown down and damaged.

or on crib-piers made of sleepers and rails. The spans varied between 17 feet and 24 feet, and the baulks used for stringers were generally 18 inches by 18 inches, 18 inches by 9 inches,

or 16 inches by 16 inches in cross-section. Similar bridges were constructed on the sites of the old ones in cases where deviations were not necessary, the rails being kept at their original level. The time taken to construct the shorter deviations was, on an average, 3 days to 4 days, working day and night, whilst 2 days was usually a sufficient time for a bridge without a deviation.

Besides these larger breaks, the enemy had blown up pairs of rails in several places, by putting charges of dynamite under the joints. The damage done in these cases was repaired very quickly.

The officers in charge of the construction party were Captain F. Fuller, R.E., during the first part of the advance, and Lieutenant H. A. Micklem, D.S.O., R.E., during the remainder of the time.

Repairs to Damaged Bridges.—With the approach of the wet season, which usually sets in about the beginning of November, it was necessary to replace the temporary bridges, which had been purposely built with greater regard to speed than permanency, by more permanent structures. In the district west of Middelburg it was decided to proceed at once with the rebuilding of the masonry, and, where possible, to patch the damaged girders. The work of rebuilding the destroyed masonry at Bronkhurst-spruit was commenced in the middle of September, 1900, and was finished by the end of December. The three 66-foot girders were not much damaged, and new ends were fitted to them; the 33-foot girder was replaced by wooden trussed beams with iron tie-rods; and traffic over the bridge was resumed in the first week in January. The masonry at Wilge River was next taken in hand, and the 98-foot centre span was lifted out of the river, where it had fallen and broken its back. The centre bay was cut out and rebuilt, and trussed beams were substituted for the two 33-foot girders. The work was ready for traffic by the middle of February. The two culverts at 250 miles and 251 miles were rebuilt, and new girders were fixed, the work in each case occupying about 6 weeks. At Van der Merwe trussed beams were used. The fixing of these and the rebuilding of the masonry occupied about 2 months. These bridges were all rebuilt under the supervision of Captain F. Fuller, R.E., who was the officer in charge of reconstruction at Pretoria.

In the low country it was impossible to proceed with the permanent reconstruction of the bridges at once. Instructions were accordingly issued for their semi-permanent reconstruction in such a manner as to be capable of withstanding any but an

exceptional flood. The bridge at Kaapmuiden was left to the last, and all energies were directed towards securing the safety of the rest of the main line. The first bridge reconstructed was the bridge at Malelane, which had been blown up by the British. The Netherlands Railway officials had constructed a short deviation, and a bridge built on sleeper crib-piers of pyramidal shape. This began to show signs of failure, towards the end of October, owing to the sinking of the footings, which had been built of sand-bags. The work of building the semi-permanent bridge occupied a little over a week, and was finished early in November. The bridge was a high timber trestle-structure on the site of the old permanent bridge. The trestles were bolted down to concrete foundations 4 feet in thickness, and were inter-braced in the usual manner. It was followed by the reconstruction of the bridges at 17, 26, and 53 miles, the semi-permanent bridges being in each case of a similar pattern to that just described.

On the 22nd October a flood occurred at Waterval Onder, which nearly carried away the temporary bridge there. This was a low trestle-bridge, and the trestles had been built on sleepers resting on a dry-stone foundation. The flood having washed away most of this foundation, it was rebuilt, of rubble masonry in cement, and the masonry was carried up about 1 foot over the top of the sills of the trestles, being finished off on the up-stream side with a cut-water. A rubble apron was also carried round each pier, and some distance up and down stream, in order to prevent the water from getting under the foundation. This work occupied nearly a fortnight, owing to the limited amount of skilled labour available. At Godwan River the eastern span had not been much damaged by the explosion, and the old girder had been raised on a crib-pier to its original height by the railhead construction party, Fig. 3, Plate 6. The western girder had been replaced by them by a trestle-bridge of four spans. The water under this girder was of considerable depth—6 feet or 7 feet in places—and the foundations of the two eastern trestles had been built of loose stones piled up to the level of the surface of the water. It was not advisable to waste time in building a cofferdam, which would have necessitated digging a new channel under the eastern span, where the river-bed is many feet higher than under the other. Frames of corrugated iron and timber were fixed at a flat angle all round the foundations of the trestles so as to leave a space of about 9 inches between the frames and the piles of stones, and this space was filled in with 5 to 1 concrete. Bags of concrete were laid all round the toe, and for some distance up and down stream. Above

water-level the trestles were built round with rubble masonry, with cutwaters similar to those at Waterval Onder. The crib-pier under the eastern girder was replaced by a trestle-pier formed of three trestle-bents bolted to concrete foundations. The work was commenced on the 5th November, and all the masonry was completed on the 25th November. On the night of the 26th the highest flood known on the river for several years occurred, the water rising some 12 feet in 10 minutes. The masonry, being quite new, was somewhat damaged, and the foundation under the centre pier was partly washed away on the low side. The damage done was very soon repaired, traffic being stopped only for a few hours. In order to reduce the effect of the scour, a weir of big stones was built across the river about 15 feet below the bridge, and was filled in with smaller stones back to the foundations of the bridge. The old girder, which had fallen across the river just above the bridge and by damming up the water had increased the effects of the flood, was removed and dropped into a hole under the lee of the west bank.

The bridge over the Kaap River at Kaapmuiden had been of somewhat unusual construction, Fig. 4, Plate 6. It had been originally a deck-bridge consisting of three Warren trusses of 100 feet span, supported by two rocking-piers about 20 feet in height. In a high flood one of the piers had been washed away and had been re-built of masonry up to the top, so that at the time when the bridge was blown up it consisted of three spans supported on one rocking pier and one masonry pier. The enemy had blown down about 12 feet of the top of the masonry pier, bringing down the ends of the eastern and central spans, but leaving the rocking-pier and the western span intact, although in a rather precarious position. The eastern girder had one bay at the inner end considerably damaged, but the rest was not much injured. The damaged end was cut off, and the remainder was jacked up into its original position, being supported meanwhile on a crib-pier, which was gradually built up as the work of raising proceeded. When in position it was supported by a strong trestle, bolted down to concrete foundations. In the centre span the girder had been so much damaged that it was impossible to make use of it; a trestle-bridge was therefore constructed. The spans being 28 feet, the stringers were partly supported on cantilever arms branching out from the trestles. The height of the piers, 48 feet, was too great to allow the bents to be made of one set of timber. Each bent was made of two trestles, the cap of the lower being spliced to the sill of the upper. The work, which was commenced

in the middle of December and finished at the end of January, was designed and carried out by Lieut. Micklem, under considerable difficulties, the fever season being at that time at its height, whilst frequent floods greatly interfered with his getting in the concrete foundations for the trestles in the centre span. The same officer also constructed the semi-permanent bridges at Malelane and at 17, 26, and 53 miles.

No attempt was made to strengthen the temporary bridge at Avoca, and at the end of the year, when it was seen that it would not stand any longer, the remains were removed. A cable way had been previously thrown across the river by the Sheba Gold Mining Company, by arrangement with the military authorities; and by this means, and by means of a punt (which was subsequently washed away), goods and passengers were conveyed across, trains running to each side of the break from Barberton and Kaapmuiden.

Maintenance of the Line.—The permanent-way on the Pretoria Eastern line is, judging by South African standards, good. As on all other railways in that country, the gauge is 3 feet 6 inches. The rails are laid partly on teak, and partly on iron sleepers. When laid on wooden sleepers they rest on small flat chairs, each secured by two coach-screws, which also grip the rail. When laid on iron sleepers the rail is secured direct to the sleeper by iron clips. The rails are of two sections; on the greater portion of the line they weigh 60 lbs. per yard, but on a portion of the line in the low country a lighter section has been used, weighing 52 lbs. per yard. The road was well kept by the Netherlands Railway Company, but suffers much from want of bottom ballast. The bridges are nearly all of standard patterns. The ironwork is somewhat light for the weight of the engines at present running, and this defect will be more apparent if the weight of rolling-stock should increase in future. The masonry of the bridges is poor throughout; the foundations are not carried far enough down; the joints are frequently several inches wide, and are stuffed with spalls, and the mortar is a very inferior kind of lime mortar. Stones having a width of bed less than half the depth of the course are common, whilst headers are conspicuous by their absence. Good sandstone and granite, and other volcanic rocks are to be had all the way along the line, and in this respect the masonry leaves little to be desired. The signalling arrangements on the Netherlands Railway system are rather more elaborate than on most of the other South African Railways. At every crossing-place there are two distant signals and a home signal, which are usually

worked from a lever stand, and are interlocked with the main points.

The maintenance of the line had to be undertaken in the face of considerable difficulties. The first essential was the organisation of a maintenance staff. The original staff of Hollanders refused to work for the British Government, and in some of the cases where they applied for their old places and were re-instated, they were not very trustworthy, their sympathies being, perhaps not unnaturally, more with the enemy than with their new employers. It was therefore necessary to appoint an entirely new staff. For this purpose there were available in the regular and irregular forces a certain number of experienced railway men, and a larger number of professed railway men who turned out to be the reverse of experienced. An arrangement was made by which soldiers were enabled to take service under the Imperial Military Railways at first at Royal Engineers' pay, and subsequently, in the case of reservists and irregulars who were satisfactory, at the rates paid to civilians. Railway men were also obtained from the other South African Colonies, and by these means the staff was eventually filled up. The maintenance gangs on the permanent-way consist of ten natives under a white ganger in charge of about 5 or 6 miles of line. In the low country, which for a considerable portion of the year is a hotbed of malarial fever, an assistant ganger was placed with each ganger in order to lessen the chance of the length being suddenly left without anyone to look after it. The length of line allotted to each permanent-way inspector is between 40 and 50 miles.

A great number of repairs to railway buildings was necessary after the railway was taken over, especially to outlying buildings, which had been much damaged by British troops as well as by the enemy. On the high veldt, where there were no trees of any description, any woodwork such as window-frames and doors had been utilized as firewood. The chief maintenance workshops are at Waterval Boven, where there is a staff of mechanics. There are also workshops at Pretoria, Middelburg, and Komati Poort.

The greatest obstacle to the proper maintenance of the line was the presence, in many places within a few miles of the railway, of an active and mobile enemy. For some months after the line was taken over by the British, the commandos still occupying positions within striking distance of the line were comparatively harmless, but towards the end of the year 1900 they were roused to greater activity, and a period ensued which was very trying to the railway staff, owing to the persistence with which they cut the

line time after time, at places within short distances of one another. In the district between Belfast and Balmoral there was a gang that showed great ingenuity in laying dynamite mines. The mechanism used was the lock of an old Martini-Henri rifle. This was laid under the rail, with the trigger cut off short and just touching the rail, so that any considerable depression of the rail would release the spring and fire the cartridge in the chamber, which in turn exploded the charge, consisting of 3 lbs. to 4 lbs. of dynamite. So skilfully were these mines laid that it was impossible to detect them even by careful examination of the road, and the mechanism was arranged with such nicety that a ganger's trolley would scarcely ever fire the charge, whilst an engine was almost certain to do so. Another expedient was to cut the line at one place, and to lay a mine some miles off in the direction from which the construction train would have to come to repair the break. This always insured considerable delay to traffic, but was not so beneficial to the wreckers as blowing up and looting an ordinary train, which was the most common procedure. On one or two occasions the line was cut by harnessing oxen to the metals, and overturning them for a length of 500 to 600 yards, until the line assumed the form of a huge spiral. This damage was very easily repaired, for by simply unwinding the spiral the rails returned to their original position, somewhat bent, but not usually so much so that they could not be straightened.

Various precautions were taken to minimise as far as possible the number of these disasters. Each section of the line was patrolled every morning by a ganger on a trolley, and by mounted troops or infantry, before a train was allowed to enter it. The first train over a section in the morning was run with four loaded trucks in front of the engine, in order to explode any mines. Bullet-proof blockhouses were built all along the railway at intervals of about 2 miles. These precautions, however, although they doubtless diminished the number of accidents, did not for some time altogether prevent them. A list of the interruptions to traffic on the eastern line, during January and February 1901, due to the exertions of the enemy, is given in the Appendix. These two months are fairly typical of the period during which the enemy showed the greatest activity. In general, a break in the line did not delay traffic for more than one or two days. Breakdown trains were kept at several stations along the line, ready to proceed to any break at short notice. The presence of the enemy interfered in another way with the proper maintenance of the line, for it was difficult to keep gangers in outlying cottages, where they were

exposed to nocturnal visits from the enemy. After a time an order was issued by the military authorities that no gangers were to live outside the outposts at the stations. This caused much inconvenience, for there is sometimes a length of 12 miles to 15 miles of railway between the stations, which it thus became more difficult to maintain properly.

As the Author left South Africa and returned to England in April, 1901, this Paper contains only a description of work done prior to that date.

After some 10 months' experience of the difficulty of improvising an entirely new staff in a foreign country, the Author is of opinion that in any future operations, during the course of which railways may have to be taken over and worked by the British Army, it would be of advantage for the Director of Military Railways to have a large and previously organised staff of experienced railway men at his disposal. Whether or not an arrangement could be come to with the great railway companies of this country, whereby a number of their employees could be enrolled in the Army Reserve, the Author is, of course, unable to say; but he has no doubt that some such arrangement might be of great benefit to the country at some future date.

In conclusion the Author desires to express his indebtedness to Major W. D. Waghorn, R.E., Superintendent of Works, Imperial Military Railways, Captain E. H. M. Leggett, D.S.O., R.E., Deputy Assistant Director of Railways, Pretoria, and Mr. A. F. Stewart, late District Engineer, Eastern Line, Imperial Military Railways, for assistance during the preparation of the foregoing Paper.

The Paper is accompanied by two drawings, from which Plate 6 has been prepared; and by the following Appendix.

[APPENDIX.

APPENDIX.

INTERRUPTIONS TO TRAFFIC—PRETORIA EASTERN LINE.

January, 1901.

January 3rd. Enemy 3 hours on line between Brugspruit and Balmoral.
„ 8th. Attack on line at number of stations between Pan and Waterval Boven. Damage at Pan and Dalmanutha; all traffic suspended and not restored until 10 January (4 P.M.).
„ 9th. Construction train, going to repair line damaged by enemy near Pan, blown up.
„ 17th. Three trains held up and wrecked, line being blown up between Brugspruit and Balmoral. Line cleared and traffic restored by 3.20 P.M. on the 18th.
„ 19th. Telegraph cut and ganger's cottage damaged near Pan.
„ 21st. Train exploded mine near Brugspruit, but got over safely.
„ 23rd. Pilot train blown up near Uitkyk. Traffic suspended owing to presence of enemy on line between Belfast and Wonderfontein; also between Elandshoek and Alkmaar.
„ 25th. Line blown up near Uitkyk, cleared 3.30 P.M.
„ 29th. Enemy on line near Uitkyk.

February, 1901.

February 2nd. Rails pulled up by enemy near Pan; slight delay.
„ 3rd. Troop-train stopped at Bronkhurstspruit owing to presence of enemy.
„ 10th. Line blown up between Uitkyk and Great Oliphants River.
„ 12th. Telegraph destroyed.
„ 13th. Coal-train derailed between Brugspruit and Balmoral and engine damaged; line cleared 2.45 P.M.
„ 15th. Line damaged between Uitkyk and Great Oliphants River; traffic resumed 1 P.M.
„ 16th. Telegraph pulled down between Brugspruit and Balmoral.
„ 19th. First down-train blown up between Brugspruit and Balmoral; line blocked till 20th.
„ 28th. Delay of 4 hours, owing to presence of enemy between Balmoral and Wilge River.

(*Paper No. 3309.*)

"History and Development of the Frias Silver-Mines."

By Arthur James Russell, Assoc. M. Inst. C.E.

In the following Paper the Author presents a short history of the Frias mines, dating from the early days of the Spaniards, giving the results of mining operations during the last 30 years, and a general description of the machinery and plant in operation and of the methods of mining employed at the present time.

The Republic of Colombia, formerly known as New Granada, occupies the north-west corner of South America, bounded on the north by the Caribbean Sea and Costa Rica, on the east by Venezuela and Brazil, on the south by Brazil and Ecuador, and on the west by the Pacific Ocean, the area being over 500,000 square miles. The country at present is divided into nine departments. In Colombia the chain of the Andes is split up into three distinct mountain-ranges, known as the Eastern, Central, and Western Cordilleras. The main waterway of the country is the River Magdalena, lying between the Eastern and Central ranges. The Western range spreads towards the Pacific coast, and is divided from the Central range by the valley of the Cauca River. The Frias mines are situated in the department of Tolima, on the eastern slope of the Central range of the Andes, at an elevation of 4,000 feet above sea-level, and 35 miles distant from Honda, the nearest port, on the River Magdalena, 600 miles from the sea-coast.

In a treatise entitled "Estudios sobre las minas de Oro y Plata de Colombia" (Studies of the Gold and Silver Mines of Colombia), by Señor Vicente Restrepo, a Colombian authority on the mines of the country, is found the first mention of the Frias mines as being worked by the Spaniards during the period in which they carried on extensive mining operations throughout the country, namely, between 1548 and 1729. Forced labour was imposed upon the Indians for the working of the mines; but later on negroes were introduced to relieve the Indians, although the

latter were still compelled to share the work by conscription, known as "Mitis," by which one in every seven men was selected for mining work. By means of this forced labour the mines were worked profitably and were very thoroughly explored, but pumping appliances being then unknown the mines were worked very superficially, the deepest workings in the district being those of "Frias" and "La Manta," which were worked to a depth of over 100 feet from the surface. The method of draining these mines was known as "ziquitumba," which consisted in carrying the water from shaft to shaft by hand, in raw-hide bags, the footway being cut in the rock. In the year 1729 the King of Spain, hearing that many Indians were dying from the work in the mines, issued a Royal mandate, on the 7th June, prohibiting that any Indian should be compelled to work in the mines. This was the death-blow to the Spanish mode of mining for silver, as with their primitive system of mining and treatment of ores the work could only be carried on profitably by forced labour, and the mines were consequently abandoned. In 1784 the Governor of the Province, in a report to the Viceroy, stated:—"The chief mines were located at Santa Ana and Lajas, although there were others at Frias and Bocaneme. All were operated with profit to their proprietors, and labour in them would not have ceased had it not been for the absolute interdiction of the 'Mitis.'"

In the year 1868, during the time that the Santana mine was being worked, the Frias mines were re-discovered, and works were commenced by Messrs. Powles, Birchall and Welton; and in the year 1871 the property was sold to the present Company, the Tolima Mining Company, Limited, who have from that date carried on mining operations on a sound industrial basis, steadily developing the property with a judicious outlay of capital, and with very successful results. During the first 15 years' working, 1868–1882 inclusive, 4,372 tons of silver-ore concentrates were produced and exported, giving a yield varying between 274 ozs. and 376 ozs. of fine silver per ton, or an average of 311·4 ozs. per ton, making a total output of silver of 1,414,128 ozs., valued at £322,594. During the following 9 years, 1883–1891, many improvements were made in ore-dressing machinery and in pumping and winding appliances for deeper sinking, and compressed-air machinery was introduced. The production of the mine during these 9 years was 6,073¾ tons of concentrates, giving an average of 315·6 ozs. of fine silver per ton, or a total yield of 1,917,027 ozs., valued at £390,335, produced at a total mine cost of £229,434, or £37 per ton of export mineral.

During the period 1892–1900, which includes the most prosperous years in the history of the mine, many additions have been made to the machinery both on the surface and underground, and the production during these 9 years has been 12,990 tons of concentrates, giving an average of 343·8 ozs. of fine silver per ton; or a total yield of 4,467,163 ozs. of fine silver, valued at £602,624, at a total mine cost amounting to £367,185, or £28 5*s.* 0*d.* per ton of export mineral. The highest production of the mine in any one year was that in 1893, when 2,660 tons of concentrates were produced and exported, yielding 1,009,193 ozs. of fine silver, giving a value of £144,520, at a total mine cost (including capital expenditure such as new plant, development works and freight to Swansea) of £67,013, or 1*s.* 3¾*d.* per oz. of silver produced. The average assay of the mineral exported was 379·39 ozs. of fine silver per ton. The total production from the Frias mines during the years 1868–1900 has amounted to 7,798,320 ozs. of fine silver, or 238·7 tons of the white metal, which has produced a value of £1,315,553. The foregoing results are shown in the form of curves in Figs. 1-4, Plate 7. These indicate graphically the work performed in relation to the output of the mine, and present a good illustration of the ups and downs experienced in "bonanza" mines.

At the present time a parallel lode, known as the Plaza lode, at a distance of 170 fathoms from the Frias lode, is being explored, and from the indications of the present shallow workings this new mine promises to be as productive as the Frias lode.

Description of the Mines.

Geological Formation and Ores.—The geological formation at the elevation and in the district of the Frias mines is composed of schists, including micaceous, chloritic and talcose varieties. The Frias veins, including the Frias, Welton and Plaza veins, are formed in these schists, with an average underlie of 70°, and with a mean strike N. 53 E., the veins varying in width between a few inches and over 20 feet. The outcrops of the veins present little indication of the extensive bodies of silver ore met with at a depth. Some free gold is found near the surface, but this metal disappears entirely at a greater depth. At several points at different depths the Frias lode has been found to be split into two or more branches by "horses," or masses of barren rock, causing curious distortions and irregularities in the underlie and width of the lode and formations of ore-bodies. The ore is met with in

"bonanzas" or bunches, varying very much in extent and yield, but almost invariably at places where some irregularity in the lode has been produced by the junction of cross-veins or "horses" which split the lode. So far it has been the experience that the largest "bonanzas" have been met with where the lode has been subject to the greatest distortion. At a point 110 fathoms below the surface the Frias lode yielded as much as 12 tons of export mineral per square fathom, assaying over 500 ozs. of fine silver per ton, which at that time was worth over £1,000, and at this point the lode was split into three branches. It is also curious to find that the grade of the ore increases with the quantity in yield.

Since the year 1881, 15,969·6 square fathoms of productive ground has been extracted from the Frias lode, which produced 23,435·7 tons of export mineral, thus giving an average yield of 1·46 ton of export ore per square fathom of productive lode, and the average grade of export mineral produced shows an average assay-value of 323·6 ozs. of fine silver per ton. To produce this quantity of export mineral, 205,026 tons of crude ore were raised to the surface and treated as described later.

Surface Works.—In considering the surface-works, the first and most important feature is the system of water-supply, which provides the motive power to all the running machinery, both on the surface and underground. In the early history of the Company's working, two short ditches were constructed to take water from the Frias stream, sufficient for two over-shot water-wheels, one being used for pumping and winding purposes, and the other for driving the mill machinery, together with a circular saw and other workshop appliances in the general repair-shop. The power thus supplied amounted to 25 HP. It was soon found that as the mine was explored in depth more power was necessary, and a high-level water-supply was then laid out at a level of 370 feet above the mine, by means of an open ditch, 5 miles in length, which tapped various streams; this provided a supply of 1,500 gallons per minute delivered at the mine, thus securing a further effective power of 100 HP. A turbine was erected to utilize this additional power for driving the winding-engine, and the first air-compressor was then erected. At a later date the turbine was replaced by a Pelton wheel, 5 feet 6 inches in diameter, which, in the Author's opinion, is the most suitable motor under the conditions met with at this mine. The frequent ·y tropical rain-storms cause the water-supply to be charged sand and vegetable matter, which, although removed to a

great extent by screens and sand-boxes, is apt to cause obstruction in the inlet- and outlet-passages of a turbine, which is not the case with the open jet-supply to a Pelton wheel.

In the year 1891 a new ditch was constructed, 4½ miles in length, to tap another stream known as the "Santa Rosa," and was connected to the high-level ditch by means of an inverted siphon, consisting of 1,333 feet in length of 18-inch pipes, passing a gulch having a depression of 320 feet vertically. Near the take of this ditch there is a shorter inverted siphon, 438 feet in length, of 15-inch pipes, crossing a depression of 200 feet. During the year 1895 this ditch was further extended for a length of 3 miles to tap other streams, which necessitated another inverted siphon, consisting of 1,200 feet in length of 18-inch pipes, crossing a depression of 300 feet vertically, with an effective delivery-pressure corresponding to a head of 18½ feet. These siphons are all fitted with air-valves to allow free entry of air in case of a sudden outrush of water through breakage, which is an important precaution to prevent collapse through the vacuum caused by a sudden outrush of water. A wash-out valve is also provided at the lowest point of the siphon, for emptying the pipe when necessary. In filling the siphon, care is required in carrying out the operation slowly, to prevent any possible air-lock, which might cause serious damage. The total cost of the last 3 miles extension of the ditch amounted to £1,475, and with the completion of this the total collective length of the waterways amounts to close on 15 miles, the original constructional cost of which may be put down at £11,250, or an average of £750 per mile.

The line of these ditches runs over very rough country, being cut on the steep hillsides, the slope of which varies between 30° and 80° with the horizon. In some places it is led by means of a tunnel through a ridge, in other sections by overhanging timber fluming round rocky precipices and through hard rock requiring blasting, and in others in soft treacherous ground requiring lining either by dry-stone walls, where stone is easily procured, or by rough timber slabs framed with round timber.

The main upper-level ditch has a carrying capacity of about 5,000 gallons per minute, and the collective supplies from the extensions will keep up the supply to 3,500 gallons per minute during the dry seasons of the year, which will give an effectual power of 250 HP. after deducting friction in the pipes and other losses in transmitting the power to the various classes of machinery. In the wet seasons of the year the water-supply required is practically in duplicate, so that any one separate branch of the ditch can

be turned off, and necessary repairs carried out, without having to stop any of the machinery.

This high-pressure water-supply is conveyed by a main pipe-line 1 foot 6 inches in diameter, reduced to 1 foot 4 inches, and branch-pipes 8 inches and 6 inches in diameter, to four Pelton wheels, viz., one in the main power-house, 5 feet 6 inches in diameter, driving the winding-engines, four air-compressing machines, stone breaker and blower; one, 3 feet in diameter, driving the dynamo for electric lighting; one, 3 feet 6 inches in diameter, driving the saw-mill and wood-working machinery, and mechanics' fitting- and turning-shop; and, lastly, a small Pelton motor, 2 feet in diameter, as duplicate motive-power for the mill and dressing machinery, and used under ordinary circumstances for driving the dressing machinery separately from the mill. The tail-races from these four Pelton wheels are conveyed in a 2-foot pipe-line to the lower ditch-level; the collective supplies are delivered to the overshot water-wheel, 36 feet in diameter, which drives the mill; and the tail-race from this wheel supplies an overshot water-wheel, 35 feet in diameter, which works the Cornish pumping system to the deep mine. The tail-race of this wheel is again taken up, and, with the additional supply from the Frias stream at this level, is conveyed by a pipe-line 2 feet 6 inches in diameter for a distance of 1,100 feet, to supply an overshot water-wheel 40 feet in diameter by 3 feet 6 inches breast, driving an additional set of air-compressing machinery.

The yearly cost of maintaining the system of waterways described in the foregoing varies considerably according to the severity of the seasons, but the average may be taken at £500 per annum. The collective power of the machinery at present being driven from this source may be taken as 230 HP., so that the cost of the power supplied works out at slightly over £2 per HP. per annum, and the Author estimates that steam-power, under the conditions obtaining at the mine, with the necessity of using wood fuel of very poor quality, would cost not less than £2 per HP. per month.

The rainfall is plentiful, long droughts being very rare. The average rainfall of the district, from observations made by the Author over a period of 3 years, shows an annual rainfall of 100 inches to 110 inches. The seasons are the following: January to March inclusive, dry; April to June, wet; July to September, dry; and October to December, wet; but at the same time there is considerable variation in these seasons. The greatest monthly rainfall registered was 14·5 inches in the month of October, and the smallest 1·5 inch in the month of January. The heaviest

rainfall registered was in 1895, when in 6 hours 4½ inches of rain fell. In calculating the power available from ditch supplies, a careful study of the minimum supply is necessary in order to be able to estimate for a permanent and constant power required, such as winding and pumping; and it is also very important to take into consideration the maximum water-supply in constructing flood-gates, overflows, and dams, at the various bulkheads where the water is taken.

The main winding-engine consists of two 6-foot drums, 1 foot in width between the flanges, arranged as fixed and loose drums. The fixed drum is geared to the belt-driven countershaft, to which is attached the brake, the loose drum being provided with clutch prongs to engage with the fast drum as required. The countershaft to which the fast drum is geared is driven from the main line of 4½-inch shafting from the 5-foot 6-inch Pelton wheel by means of two 6-inch belts, one straight and one cross, by which the engine is reversed. The average speed of winding is 150 feet per minute, the weight of the loaded skip is 1½ ton, and the depth of the shaft is 194 fathoms. A small winding-engine with a drum 2 feet in diameter, driven from an overhead countershaft, is used for raising the ore delivered at the pit-mouth up the incline to the ore-passes.

The pithead frame is a light wrought-iron structure having a total height of 35 feet from the surface of the ground to the centre of the sheaf-pulleys, which are 7 feet in diameter. It was constructed in small sections for mule transport, and its total weight does not exceed 7 tons. The foundation is formed by two wrought-iron box-girders which span the mouth of the shaft, being built into the brickwork collar.

The air-compressors, driven by the 5-foot 6-inch Pelton wheel, consist of one double-cylinder belt-driven compressor, 12 inches by 12 inches, and one duplex compressor, 12 inches by 24 inches, geared to the belt-driven countershaft, and one direct belt-driven double-cylinder compressor, 10 inches by 16 inches, run at a speed of 120 revolutions per minute. The air-compressors driven by the 40-foot diameter overshot water-wheel consist of four compressors, 18 inches in diameter, and 6 feet stroke, driven direct from cranks on the main shaft of the water-wheel at a speed of 5 revolutions per minute. The water-wheel is of ironwork, with the exception of the arms, and is 5 feet 6 inches breast. The delivery air-pipes from all the compressors are connected with one another from the various air-receivers and distributed to the two mines as required.

The machinery in the fitting- and repair-shop consists of two lathes, one metal-planer, one drilling machine, and one screw-

cutting machine, worked by a 3-foot 6-inch Pelton wheel, which also provides power for the wood-working machinery, viz., a circular saw, wood-planing machine, and shingle-sawing machine.

The ore-dressing machinery is worked by an overshot water-wheel, 36 feet in diameter and 4 feet 6 inches breast, on a 6-inch shaft, the power being transmitted by a pinion and internal spur-wheel, and by belting from the pinion-shaft to the main line of mill shafting. This wheel is supplemented by a 50-HP. Pelton motor, 2 feet in diameter, working under a head of 400 feet. This is used for driving the jigs and buddles separately from the Cornish crusher-rolls, but is so arranged that in case of emergency it can be employed to drive the whole of the machinery by changing the belt to the main shafting. This motor runs at a speed of 736 revolutions per minute in producing 50 HP., and only consumes about 600 gallons of water per minute.

The Cornish pumping system is driven by an overshot water-wheel 35 feet in diameter, 5 feet 6 inches breast, on an 8-inch shaft, the sweep-rod being connected direct to a crank on the wheel-shaft, and runs at 4 revolutions to 6 revolutions per minute, according to the requirements of the pumps. The length of the stroke is 6 feet, but can, if necessary, be shortened to 5 feet.

The dynamo is run by a separate Pelton wheel 3 feet in diameter, working under a head of 350 feet, supplied by a 3-inch pipe from the main 16-inch pipe.

Underground Workings and Methods of Mining.—The engine shaft of the Frias mine is sunk vertically from the surface to a depth of 14 fathoms, lined with brickwork, and measuring 11 feet by 5 feet in the clear. At this point, the deep adit, the shaft intersects the lode, and is continued on the underlie of the lode to a total vertical depth of 180 fathoms, levels or galleries being driven on the lode east and west from the shaft every 10 fathoms, as shown in Fig. 5, Plate 7, which gives a longitudinal section of the workings as surveyed up to the end of 1900. From the deep adit downwards the dimensions of the engine shaft are 13 feet by 7 feet, divided into two compartments, one for the double skip-road, which occupies 5 feet, and the other for the pumps, air-pipes, and ladder-way.

At the 30-fathom level is the first pumping-station, where there is a 10 inches diameter plunger-pump connected to the overshot water-wheel by means of 8 inches by 8 inches timber rods guided on the underlie of the shaft from the 30-fathom level to the adit level, where the direction is changed to the vertical by means of a wrought-iron angle-bob. From the deep adit it is connected to the angle and balance-bob, and from there it is carried on the hori-

zontal line to the crank of the wheel. This pump raises the water from a cistern which receives all the water raised from the lower workings to the deep adit, a vertical height of 30 fathoms, and thence it drains by gravitation to the surface. The capacity of this pump at the usual speed of the water-wheel is about 90 gallons per minute. At the 50-fathom level a second balance-bob is fitted to counterbalance the weight of the pump rods, and at the 60-fathom level the second plunger-pump, 8 inches in diameter, capable of raising 60 gallons per minute, delivers the water from a cistern to the 30-fathom cistern above. At the 90-fathom level the third plunger-pump, 8 inches in diameter, raises the water to the 60-fathom level, and at the 130-fathom level a 6-inch plunger-pump, capable of raising 30 gallons per minute, delivers to the 90-fathom cistern. Below the 130-fathom level the water is raised by three small Cameron pumps, having 3½-inch plungers, 7 inches stroke, fixed at the 150-, 170-, and 180-fathom levels, and worked by compressed air under a pressure of 50 lbs. per square inch. In addition to the Cornish system of pumps between the surface and the 130-fathom level there is, at the 30-fathom level, a horizontal Cameron pump having a 5-inch plunger, 13 inches stroke, capable of raising 90 gallons per minute to the adit. At the 70-fathom level there is a Worthington pump capable of raising 60 gallons per minute, having duplex 3½-inch plungers, 10 inches stroke, and at the 90-fathom and 120-fathom levels there are two smaller Cameron pumps with 3½-inch plungers, 7 inches stroke.

These pumps are worked by compressed air under a pressure of 50 lbs. per square inch, and their delivery-pipes are arranged in such a manner as to maintain the mine in fork in the event of the Cornish pump having to be stopped for any necessary repairs. Thus the drainage of the mine is provided with duplicate pumping power from the 130-fathom level to the surface. It may be said that quite 75 per cent. of the water in the mine is met with above the 90-fathom level, and from the 130-fathom level downwards the water drained to the engine shaft does not exceed 15 gallons per minute. By the system of working the mine by levels driven from the engine shaft, all the water is drained by gravitation to the various pumping-stations in the shaft already described, and in sinking winzes from one level to another small Cameron pumps and Holman hoisting-engines worked by compressed-air are employed with good results, showing great advantages in economy and speed of sinking as compared with the old-fashioned windlass worked by hand labour.

In addition to the engine shaft, a second shaft known as the

"Esperanza" was sunk at a distance of 74 fathoms to the east, and communication with this shaft has been maintained by winzes connecting the different levels of the lower workings east of the shaft; the mouth of this shaft being at a lower level than the engine shaft a good natural ventilation is secured, supplemented by the exhaust air from the various pumping- and hoisting-machines worked by compressed air. The "Esperanza" shaft also serves as a second exit from the eastern workings of the mine in case of any accident to the engine shaft. The dead-ends being worked, which require artificial ventilation, are, before being connected with the upper level by winzes, supplied with compressed air by 1½-inch, 1¼-inch, and 1-inch steam-pipes, taken from the main supply-pipe in the engine shaft. The levels driven from the engine shaft are 7 feet in height by 5 feet in width, the width being increased when the nature of the lode makes it necessary. The levels are laid with tram-lines having rails weighing 12 lbs. to 15 lbs. to the yard, for wrought-iron cars capable of carrying about ¾ ton of ore. At the junction of each level with the engine shaft, tip-plats are cut out on the footwall of the shaft, below the sole of the level, to serve as loading stations, and also at the pumping stations for the water cisterns. It is usual to connect the levels by winzes about every 35 fathoms or 40 fathoms, for the purposes of proving the ground and for ventilation, and also to facilitate the extraction of ore where the ground is proved productive. A double skip-road, with a width of 5 feet, is laid on the west end of the shaft, the skips in use being capable of carrying about ¾ ton of ore. The ore is found in "bonanzas," or bunches, varying very much in extent and yield. When the ground has been proved and opened out by the levels and winzes, the productive ground is extracted by the system known as back-hand stoping, working from the roof of the level upwards. Upon reaching a level of 10 feet or 12 feet above the roof of the level, timber stulls, formed of hewn timbers, 8 inches by 8 inches, 10 inches by 10 inches, and 12 inches by 12 inches (according to the width of the lode) are put in from wall to wall at the level of the roof, or generally slightly higher, to allow for renewing the timbers later on when decayed. These are floored with 2-inch planking. As the stope is carried up, the poor portion of the ground broken is used for filling up on the stull, and ore-shoots are formed at convenient distances with timber passes for filling the coaches, which are trammed direct to the tip-plat at the engine shaft. By this system the ore is handled the least number of times possible, the ground is drained

as the work is carried forward, and by filling up the stoped ground as the work proceeds the necessity of much timbering is avoided and safety for working is secured; also the deads from other exploratory workings above can be easily disposed of by tipping through the winzes and passes without the necessity of hoisting to the surface. For the purpose of sorting the poor stuff from the ore, temporary planks are laid on the filling under the stopes. Under-hand stoping, or stoping from the sole of the level downwards, is only resorted to under special circumstances, such as taking away arches left to support ground, or to avoid taking away ground which has proved to be unproductive. The aggregate length of all the levels driven during the past 30 years, on the Frias lode, amounts to about 7 miles, without taking into consideration the workings of the Spaniards, which, for the most part, are now inaccessible.

The Plaza mine may be called the offspring of the old Frias mine, being still in its infancy as far as the development works are concerned. It is a distinct lode, running parallel with the Frias lode at a distance of about 170 fathoms to the north, and has been under development since the year 1893, when the cross-cut driven from the surface cut the lode at a distance of 55 fathoms. After exploring the lode, which was unproductive to the west, another cross-cut was driven to the south, which within a short distance cut another branch of the lode, and soon proved productive of very high-grade mineral, assaying 800 ozs. of fine silver per ton. The productive ground only continued for a length of 2 fathoms. By hand tackle a winze was then sunk on the productive lode for a depth of 40 feet, when it became necessary to apply power and artificial ventilation for further exploration. It was then decided to utilize the compressed-air power supplied from the air-compressors, driven by the 40-foot overshot water-wheel. Pipes were connected to the Plaza mine, and, by means of a Cameron pump and a Holman winch, sinking operations were continued, with ample power and ventilation, and the No. 2 level, 10 fathoms lower than the adit, was driven upon the winze reaching the requisite depth. By the end of 1897, 207 fathoms of levels had been driven, of which 26 fathoms were productive of high-grade ore, assaying over 700 ozs. of fine silver per ton. The total expenditure up to this date amounted to £2,633 14*s.* 7*d.*, against which £2,199 worth of ore had been extracted, and the ore reserves opened out were estimated to be worth £8,386 9*s.* This gave good reason to consider very favourably this new mine; it was therefore decided to sink a vertical

shaft from the surface at such a position as to cut the No. 2 level, 56 fathoms east of the winze, and at such a level as would enable the construction of a tram-line of suitable gradient direct to the Frias mill; and at the same time to start a deep adit from the surface to drain the mine to the No. 2 level to a point in the Frias stream further east. These works were successfully carried out and the development of the mine was continued in depth; and at the present date the mine has reached the No. 4 level, or 20 fathoms below the No. 2 level, where rich ore is being found. The cost of sinking the vertical shaft 26 fathoms, to the dimensions 9 feet by 5 feet in the clear and timbered for a depth of 12 fathoms, including the value of the hoisting-machine and surface-plant, amounted to £628. The shaft was commenced on the 23rd May, and reached the No. 2 level on the 29th September. At the present time the lowest level (No. 4) is being drained to the deep adit by a Cameron pump 5 inches in diameter of plunger and 13 inches stroke, the water raised being 25 gallons per minute. A timber ore-pass is constructed at the deep adit, where all deads are tipped and dumped to the surface, the ore alone being raised to the mouth of the shaft, where it is delivered into ore-passes, and thence conveyed by mule traction to the ore-passes of the Frias mill. At present the hoisting-engine is a single 6-inch cylinder Holman engine, worked by compressed-air, and raises to the surface 20 tons per 10 hours' working. Up to the present the total capital expended on the Plaza mine has amounted to £6,000; against this outlay, ore to the value of £7,347 has been extracted, and the present reserves intact are estimated at £5,335, with good prospects of largely increasing these reserves in the immediate future. It is now proposed to further extend the surface-works to provide for a Cornish system of pumping and more powerful winding-engines, with a double skip-road for increasing the output from the shaft.

Treatment of Ore, and Dressing Machinery.—The crude ore, as raised from the Frias mine, is delivered into the ore-passes above the picking-floor, and from there the first separation is made by hand-picking at what is known as the "grate," composed of 1-inch round iron bars, spaced $1\frac{1}{4}$ inch apart. The operation of picking the ore is performed by women and boys standing on each side of the table in front of the grate, while two men rake the ore slowly over the grate under a supply of water; the small stuff with the water passes through direct to a wooden tank below, from which the ore is shovelled out to the pass underneath, and the water and slime overflows into small launders, and is conveyed by gravitation

direct to the dressing machinery. What remains above after passing over the picking-grate is then sorted into four different classes:—1. Waste, which is thrown direct into a tram-coach and dumped; 2. Milling ore; 3. Cobbing ore; and 4. Solid mineral. The milling ore is passed through a 10 inches by 7 inches Blake stone-breaker, having the jaws set to a discharge of 1¼-inch to 1½-inch, and which, when running at 90 revolutions per minute, will crush 5 tons to 6 tons per hour. From the stone-breaker the crushed ore is delivered by a shoot into the ore-bin below, which receives the fine stuff from the grate, and is then ready to be conveyed by tram to the Cornish crusher-rolls. The cobbing ore is hand-cobbed by women, and the waste resulting is passed back to the stone-breaker as milling ore. The solid mineral is passed through a small stone-breaker to reduce it to the requisite size for sampling and packing, and is ready for export. The milling ore, having been trammed to the mill, is fed by hand to the Cornish crusher-rolls No. 1, or coarse crusher, and, after crushing, the ore is raised by an endless belt bucket-elevator to the first classifier—a revolving trommel-screen having cast-iron ends, and covered with steel plates, perforated with 7-millimetre (about ¼-inch) holes, Fig. 6, Plate 7.

The ore that is too coarse to pass this first screen falls back to the rolls for re-crushing, and the remainder goes on to the next trommel-screen, which has 6-millimetre holes; the ore which does not pass this second screen is delivered to the first set of four compartment plunger-jigs, and that which passes goes on to the next trommel-screen, which has 5-millimetre holes. What does not pass this third screen is delivered into the second set of jigs, and what passes goes to the fourth trommel-screen having 3-millimetre holes; the ore that does not pass this fourth screen goes to the third set of jigs. For the remaining three sets of jigs the ore is further classified by a series of "spitzkästen" or pointed settling-boxes. The first box is narrow, causing the water to flow swiftly, thus allowing only the coarser portion of the material to sink, while the balance is carried on into the second, wider box, where with the larger area the water assumes a slower motion, allowing the next finer sand to settle, and so on with the third box, which is again wider than the second. Middlings and tailings from the jigs which are worth working are returned to the mill and re-crushed in the chat-mill, or Cornish crusher-rolls No. 2, which is arranged for finer crushing, and are then passed through a 2-millimetre revolving screen. Formerly the crushed ore from the chat-mill was delivered into the fifth set of jigs, but lately an

improvement has been made by delivering to a separate three-compartment jig. All material too fine for treatment in the jigs flows on direct to three round convex buddles supplied with another set of "spitzkasten" classifiers, of larger area than those which supply the fine jiggers. The concentrates produced from the first boxes of the six sets of jigs are now ready for export, after a final hand-washing on a flat buddle to remove any small amount of slime that may have been formed; the produce from the second boxes is generally rich enough also for export, but when too low in grade is re-crushed in the chat-mill. The produce from the third and fourth boxes is returned to the chat-mill, and the overflow from the fourth boxes is carried to the river as waste. The Cornish crusher-rolls No. 1, or coarse crusher, consists of two shells, 2 feet in diameter, 1 foot 2 inches in width on the face, and 3 inches thick, made of chilled cast-iron, and keyed on to a cast-iron core with shaft. When running at a normal speed of 5½ revolutions per minute, the crushing capacity is 5 tons to 6 tons per hour. The chat-mill, or fine crusher, is of the same form and dimensions as the coarse crusher, but with the rolls set closer, and when they crush too coarse, from uneven wear, they are passed on to the coarse crusher, in exchange for a new set of shells. The average life of the crusher-shells may be taken as 10 months' work in the chat-mill, and 2½ months in the coarse crusher, working, say, 10 hours per day. The classifying trommels are 4 feet 6 inches in length by 2 feet in diameter, and run at a speed of 20 revolutions per minute. The jigs in use were designed by Mr. George Green, of Aberystwith, South Wales, and consist of three double sets of four-compartment jigs, located directly below the classifying trommel-screens. Each compartment is divided into two, one to receive the screen, while in the other a flat plunger is worked from an eccentric running at a speed of 220 revolutions to 240 revolutions per minute; the rapid motion of the plunger conveys the pulsation of water through the screen, and effects the separation of the mineral, which falls into the inverted pyramidal-shaped compartment below the screen. From this compartment the concentrates are emptied into a tank or hutch below, by opening a valve from time to time. The eccentrics are adjustable for regulating the length of stroke to the plunger. It is found that the finer ore requires a slightly increased speed as compared with the coarser ore, thus for the first three jigs the speed is regulated to 220 revolutions, and for the last three to 240 revolutions per minute. For the satisfactory working of these machines it is very important to maintain a

constant speed. Formerly they were worked from the overshot wheel which drives the crushers, but a great improvement was effected by erecting a separate Pelton motor for working the jigs and buddles separately from the crushers. The motor is of sufficient power to drive the whole of the ore-dressing machinery if it is required to stop the overshot-wheel for repairs at any time. In addition to the three buddles already described, there are nine others in the upper buddle-sheds, which are employed in working over the slimes produced in the first three. These buddles have a diameter of 15 feet, with a centre cone 2 feet 6 inches in diameter on the top, 2 feet 9 inches in diameter at the base, and 1 foot 4 inches in height; the speed of the buddles should be 10 revolutions to 12 revolutions per minute. The slimes produced from the first three buddles are divided into three classes, viz.: heads, middles, and tails. These are then delivered to the other buddles in which the heads require treatment once to form a head of export mineral, the middles three times, and the tails four times, taking the average class of ore treated. The concentrates from the buddles are then treated in a "dolly" tub as the final treatment. This apparatus is a wooden barrel 4 feet in diameter on top, and 4 feet in depth, with a mixer worked mechanically at a speed of 28 revolutions per minute. The ore is fed into the tub with a sufficient quantity of water, and, when well mixed to the proper consistency, the mixer is quickly removed and two hammers are put to work. These hammers are worked by an eccentric on a rocking-shaft, and produce 340 blows to the tub per minute. When the charge of ore is well settled, the machine is stopped, the water is run off by a siphon, the top of the slimes or the poorer portion is removed for re-washing, and the remainder is then ready for drying and packing. The weight of the charge to the dolly tub is 2·25 tons, and the export concentrates produced weigh 1·42 ton, or when dried, 1·25 ton. The slime concentrates produced contain on the average about 10 per cent. of water, and are dried on a pair of open pan-dryers, 8 feet in length by 2 feet 10 inches in width, and 7½ inches in depth. The drying of 10 tons of slimes requires 124 cubic feet of wood-fuel, at a cost of 10 cents gold (*5d.*) per ton. The overflow- and tail-water from the twelve buddles is now conveyed by wooden launders to a series of ten shallow slime catch-pits, or settling-tanks, having a total settling area of 2,436 square feet, and a depth of 1 foot. The slime ore produced from these catch-pits is treated by an additional set of three buddles in the lower buddle-shed.

Although it is difficult to give precise figures representing the

actual work accomplished by the concentration processes described in the foregoing, since the ore brought to the mill is of such a varying nature in respect of both quality and quantity, yet the following results taken by the Author over a period of 4 months during the year 1895 represent what may be considered an average period as regards quality and output from the mine during the past 9 years:—

	Tons.
Average monthly output of crude ore as raised to surface	1,262·4
" " " jig concentrates	58
" " " slime concentrates	38·5
" " " cobbed mineral	23·5

being 120 tons of concentrates produced from 1,262 tons of crude ore as broken from the lode.

In concentrating this ore, the average assay of the classified ore delivered to the first boxes of the six sets of jigs gave 57·26 ozs. of fine silver per ton, which gave the following results in concentration:—

	Fine Silver. Ounces.
Average assay of concentrates from first boxes . .	260·23
" " " " second boxes .	84·92
" " " " third boxes . .	48·44
" " " " fourth boxes .	27·42
Tailings from overflow of fourth boxes	6·58

The average assay-value of the slimes received by the first three buddles during the same period showed 54·4 ozs. of fine silver per ton:—

	Fine Silver. Ounces.
Heads of slime concentrates produced	158·96
Middles of " " "	35·27
Tails of " " "	11·31

Previous to the construction of the catch-pits and the three lower buddles, the overflow and tailings from the twelve upper buddles went straight to the river. The total cost of the new buddles amounted to £547, and they produced 5 tons per month of slime concentrates during the first year, at a net profit of £14 per ton, thus paying for this addition to the dressing-machinery in 8 months' working. The greatest production of mineral occurred in the year 1893, when, on an average, 1,503 tons of ore per month was raised from the mine, which produced, on an average, 221·6 tons of export mineral, made up of the following:—

	Tons.
Cobbed mineral	76·8
Jig concentrates	98·3
Slime concentrates	46·5
Total	221·6

The dressing-cost in labour, calculated on the quantity of crude ore raised from the mine, works out at only 2*s.* 1*d.* per ton; as calculated on milling ore, 3*s.* 5*d.* per ton; and as calculated on export mineral produced, 13*s.* 8*d.* per ton. The average value of the mineral produced was £54 10*s.* per ton. Labour for most of the ore-dressing operations is obtained at very low cost by the employment of women and small boys, and the dressing-labour cost given in the foregoing will compare very favourably with such operations in any part of the world, and it is for this reason that the concentration of the slimes can be carried on so efficiently by the system of buddles. The dressing machinery, as described, was supplied by Mr. George Green, of Aberystwith.

Upon studying the general plan and arrangements of all the surface-machinery, many improvements may suggest themselves, if it were re-designed to all the requirements at the present date, which might facilitate in some details the handling of the ore; but it should be borne in mind that the present establishment is the result of a steady development during a period of over 30 years, and under such circumstances it is difficult to build up such a work to meet the requirements of an uncertain future.

Labour and General Organization of the Work.—The general establishment is divided into the following departments:—

1. Surface and general works department; with the sub-departments mechanics', smiths', carpenters', ditch-maintenance, and surveying and designing of new works.
2. Underground department.
3. Ore-dressing department.
4. General office work and stores department.

Besides these principal departments, there is the management of the house and land property, including outside contracts for timber, fuel, freight, and maintenance of roads. For the general management of the establishment there is a European staff, twelve to fifteen in number, with a staff of native employés and work-people varying in number between 350 and 500, including all classes of work in connection with the mine. A medical officer is also appointed, resident at the mine; and dispensary and hospital accommodation is provided for the benefit of the employés. A large

supply of all necessary mining stores is kept on hand, as it is not possible to procure many articles in the country, and communication is sometimes interrupted by revolutionary movements or other causes, when the mine is entirely dependent on the resources of the establishment.

Transport and Communication.—The distance from the mines to Honda, the postal town, and the nearest port on the River Magdalena, is about 35 miles, 15 miles of which is over a very broken mountainous road which is maintained at the cost of the Company for mule transport; and the remaining 20 miles is over plains, 15 miles of which is now used for wagon and ox-cart transport. The export mineral is packed in tarred hemp bags, weighing, when packed, 140 lbs. each, two of which form a cargo for mules or oxen. All machinery has to be designed especially for mule transport, in packages not exceeding 200 lbs. weight, although special pieces weighing as much as 700 lbs. have been brought up by special contrivances, though at a very high cost. All freight is given out in contract, both for carrying the mineral and bringing up stores and machinery from Honda. During the last 9 years, including mineral and stores and machinery, 13,000 tons have passed over the road for the mine on mules and oxen. The establishment is connected with the general telegraphic system of the country, and is therefore in touch by cable with London.

The Paper is accompanied by four photographs; and by three drawings, from which Plate 7 has been prepared.

(*Paper No. 3292.*)

"The Maintenance and Renewals of Waterworks."

By RICHARD PRICE-WILLIAMS, M. Inst. C.E.

THE fuller and more detailed information which during the last 30 years has been furnished regularly in the published Reports of the London Waterworks Companies, and in the returns made by these Companies to the Local Government Board, "in pursuance of the Metropolis Water Act of 1871," affords the means of ascertaining with a greater degree of accuracy the average annual cost of the maintenance and renewals of the works, plant and machinery, and of determining their average serviceable life by means of the relation between the cost of their maintenance and renewal during this long period, and their first or capital cost.

As directly bearing upon this question it may be mentioned that, during the period dealt with, the water-supply of the metropolis has been nearly doubled, to meet the requirements of the unprecedented growth of the population, which in the last three decades has added nearly 2½ millions to its numbers, mainly in outlying suburban districts within the water-supply area of these Companies. During the first of these three decades (1871–1881) the increase amounted to 881,021 persons, an addition in the short space of 10 years almost equal to that of the entire population of London at the beginning of the century just closed,[1] and considerably exceeding that of the city of Glasgow at the date of the last census.[2] The increase during the second decade was nearly as large, viz., 866,671, exceeding the entire population of Bir-

[1] Popular London, 1801, 958,867.
[2] Glasgow, 1901, 775,601.

mingham and Sheffield combined,[1] while during the concluding decade of the century the increase, although estimated by some authorities to be not quite so large, will certainly exceed ¾ million.[2] To have succeeded, therefore, as these water companies have done without apparent difficulty and without any interruption or diminution of the water-supply, in meeting the additional requirements of these successive large increases of population, cannot but be regarded as a remarkable achievement, highly creditable to the engineering skill and resource of the companies' executive. The large increase in the water-supply has necessarily been attended by a corresponding, and even a greater, increase in the annual expenditure on maintenance and renewal of the works and plant, with, however, only a slight increase in the expenditure per million gallons, to which reference will be made later.

Under the head of "Maintenance," in the water companies' reports, are included large items such as rates and taxes, Thames and Lea Conservancy, and rents, amounting altogether to about 35 per cent. of the so-termed "Maintenance" expenses, which, having no relation to the subject of this Paper, have been disregarded. There is, however, no separate heading for renewal expenditure on works, plant, etc., which, it is submitted, is included in the maintenance expenses; the sufficiency of this arrangement the Author will endeavour to demonstrate.

The items of expenditure properly attributable to maintenance and renewal of the works and plant, which, as a matter of convenience, will continue to be described as "Maintenance," are the following:—

(1) Storage. The cost of repairs and renewals of reservoirs.

(2) Distribution. The cost of repairs and renewals of existing water-mains, service-pipes, etc.

(3) Pumping, so far as relates to the cost of repairs and renewals of pumping-engines and other plant and machinery connected with the supply of water for domestic and other purposes.

(4) Filtration. The cost of repairs and renewals of filter-beds, etc.

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[1] Birmingham, 1891	505,772
Sheffield ,,	351,848
Total	857,620

[2] The preliminary census returns for 1901 show that the increase in "Greater London" has been 970,555, which, with the estimated increase in the extra area of "Water London," would exceed 1,000,000.

(5) Salaries. The salaries and wages of those engaged in the maintenance and renewals of the works, plant, etc.[1]

Although in the Tables given in the Appendix the maintenance expenses under these several headings are given for each Company separately, it is necessary, for the purposes of this Paper, to treat the works and plant of each company as forming an integral portion of one great system of water-supply within the metropolitan area. The fluctuations in the capital, revenue and working expenses, management expenses, and maintenance expenses of this great system during the last 30 years are shown, respectively, in Figs. 1, 2, 3 and 4, Plate 8.

The principal item, namely, "Pumping," constitutes on an average 43 per cent. of the entire maintenance expenditure. During the last 30 years the sum of £4,408,846 has been expended out of revenue on pumping operations and on the maintenance and renewals of the pumping-engines and machinery, which during that period have supplied the Metropolis with 1,745,718 million gallons of water for "domestic and other purposes," Appendix, Table A 2; thus the cost of the pumping alone has been, on an average, £2 10*s.* 7½*d.* per million gallons, or 0·000606*d.* per gallon, Appendix, Table B 2. The item of "Distribution," or the cost of repairs and renewals of the water-mains and pipes, amounted to £2,964,127, or an average of £1 14*s.* per million gallons, Appendix, Table A 2. These two items together constitute nearly three-fourths of the entire maintenance expenses. The total length of water-mains and pipes laid at the end of 1899 was 5,349 miles. Taking therefore the mean pipe-mileage during the three years 1897–1899 (5,333 miles) and the mean annual expenditure on its maintenance, the average cost per mile of water-main or pipe-way (adopting the analogy of a railway, whose function as a means of conveyance or as a conduit for traffic is the same) is £24 5*s.* 5*d.*, Appendix, Table C.[2] The total expenditure during the 30 years on repairs and renewals of filter-beds, viz., £567,334, although comparatively small in relation to the quantity of water supplied (£0·32 per million gallons) bears striking testimony to the greater attention now given to this important branch of waterworks business, the amount now spent

[1] The item of maintenance superannuations has been transferred in the Local Government Board returns to "Management" expenses, and is similarly dealt with by the Author.

[2] $\frac{£129.432}{5,333} = £24\ 5s.\ 5d.$

annually on filtration being four times as much as that spent in 1871, while the cost per million gallons then and now is £0·19 and £0·37 respectively, Appendix, Table A 3. The remaining items of "Storage" and "Salaries," amounting to £643,615 and £1,709,694 respectively, make up the total to 10¼ millions, equivalent to an average annual expenditure of £343,121 in pumping operations and on the repairs and renewals of existing works and plant, for their maintenance in an efficient condition for the special business which these Water Companies for nearly a century, and in some cases for a much longer period, have been engaged in, of supplying the Metropolis with one of the chief necessaries of life, Appendix, Table A 2.

The cost of the maintenance and renewals of the pumping-engines, boilers and engine-house plant, which is included in the "Pumping" expenditure (except in the cases of the Grand Junction and Southwark and Vauxhall), is not shown separately in the water companies' accounts; but from the close agreement in the particulars of the actual expenditure on their repair and renewal during the last 10 years, kindly supplied to the Author by the executive of four of the companies, it may be safely assumed that it amounts, on an average, to one-fourth of the entire pumping expenditure of these six companies; in the case of the other two companies referred to, the cost of the engine repairs and renewals is included in the item of "Distribution." The total expenditure on the maintenance and renewal of the operating works and plant of the London Water Companies, in the aggregate, during the last 30 years, has therefore amounted to nearly £7,000,000, or an average annual expenditure of £223,125 (Appendix, Table A 2), and to £3·83 per million gallons, a rate which, if maintained, would suffice to recoup the entire "capital raised" by these companies (averaging £236·70 per million gallons during that period) in about 62 years. An appreciable increase in the cost of maintenance per million gallons is noticeable, viz., from £3·26 in 1871 to £4·07 (the average of the last 3 years), an increase of 24·35 per cent.

The first or capital cost of the various works, plant, and machinery, for the maintenance of which this large annual expenditure has been made, is not disclosed in the published reports of these companies. In two instances only, those of the Lambeth and West Middlesex Companies, is the cost of the land given separately, where it is shown to have amounted to just 1 per cent. of the total capital expenditure. As, however, the capital expended by each of the Companies is somewhat in excess of the

"capital raised," by reason of the amount of the premiums received on share issues having been expended as capital, it is evident that the amount raised will more nearly approximate to the actual cost of the works and plant; as, whatever the actual difference may be, the ratio of the one to the other would practically remain unaltered, so that the ratio which each year's expenditure on repairs and renewals bears to that year's total "capital raised" per million gallons, would give a close approximation to the average serviceable life-period of the works at that particular time. As an illustration of this, in 1871 the total amount of capital raised was £10,009,903, equivalent to £256·11 per million gallons of water supplied that year, and as the annual expenditure in repairs and renewals was then £3·26 per million gallons, it follows that if the annual expenditure was continued at that rate it would suffice to recoup the entire capital raised in 78½ years, Appendix, Table A 1. The additional capital raised since 1871, mainly expended on extensions into new districts within the area served by the Companies, amounted to £8,375,037, an average annual increase of £288,794, or a little over 2 per cent. per annum, whereas the increase during the same period, both of the water-supply and of the annual expenditure on repairs and renewals of the existing and subsequently constructed works, has, as already stated, been much greater. The effect of the more rapid increase in the water-supply, during the 30 years, has been to reduce the amount of the capital raised per million gallons to an average of £236 14*s*., or in other words, a considerably less amount of capital has since been required to produce a supply of a million gallons of water. This, combined with the still more rapid increase in the maintenance expenditure to £3·33 per million gallons (inclusive of the cost of the maintenance of the newly-constructed works-plant), has shortened the period of the capital recoupment and the nominal serviceable life of the works to a little under 62 years, Appendix, Table A 2.

During the latter part of the period, however, the rate of increase both of the water-supply and of the maintenance expenditure has largely exceeded the average. With the view therefore of ascertaining the present relation between the annual maintenance expenditure and the capital outlay on the works and plant, the average expenditures during the three years 1898-1900 inclusive are given in the Appendix, Table A 3, from which it will be seen that, the lower rate of increase of the "capital raised" as compared with that of the water-supply having continued, the capital raised per million gallons has been still further reduced to £229·68,

while the cost of "maintenance," which has more than kept pace with the rate of increase of the water-supply, has reached the high average of £4·07 per million gallons, which, if maintained, would recoup the capital raised in 56½ years.

Although the estimated serviceable life-period of the works and plant of the various Water Companies considered as a whole approximates to the actual period of their complete renewal, considerable differences in the lengths of these periods are met with in the case of some of the companies, notably in that of the Chelsea Company, where, mainly owing to the combined effects of the relatively small and slow increase of its water-supply and a more rapid increase in the amount of its capital, the "capital raised" per million gallons, which in 1871 amounted to £270·73, has increased to the exceptionally high average of £321·64, the increase having been maintained throughout the whole of that period. However, by the more rapid increase in the maintenance expenditure, the period of recoupment of the capital has been shortened to 86 years, Appendix, Table A 2. During the last 3 years (1898-1900 inclusive), owing to the absence of any appreciable increase in the "capital raised," combined with a more rapid increase in the water supplied and in the maintenance and renewal expenditure, the "capital raised" per million gallons has been reduced to £287·79, a much nearer approach to the average, and the serviceable life-period to 80 years, Appendix, Table A 3. This Company has still the largest capital per million gallons, and the lowest maintenance expenditure per million gallons of any of the companies. Notwithstanding this, however, there is every indication that adequate provision has been and continues to be made for the renewals of the works and plant, Appendix, Table A 2.

The shortest period in which the maintenance expenditure would recoup the capital raised is met with in the case of the Kent Company, viz., 48½ years; the amount of the capital of this Company per million gallons throughout the entire period has been a minimum, and its maintenance expenditure in similar terms almost a maximum, the effect of which, with a maximum rate of increase in its water-supply, has been to reduce the capital per million gallons from the comparatively low average of £184·41, at which it stood in 1871, to £155·08 during the three years 1898–1900; the average during the entire period has been £190·60 per million gallons as compared with £236·70, the average for the eight Water Companies combined, Appendix, Table A 2.

The New River Company, however, the doyen of the London

Water Companies, with by far the largest amount of capital, and, with the exception of the Chelsea Company, the largest capital per million gallons, and excepting the East London Company the largest water-supply, furnishes, as might be expected, results more nearly approaching the average period of recoupment of its large capital, and average life-period of its works and plant. Owing to the rate of increase of its water-supply somewhat exceeding that of its capital raised, the "capital raised" per million gallons has been reduced from £306·214 in 1871 to £291·74; this, combined with the large concurrent increase in its maintenance expenditure, has shortened the period of capital recoupment from 67½ years, at which it stood in 1871, to 59½ years, the average maintained during the last 30 years. During the last 3 years the serviceable life-period has been still further shortened to 51 years, which corresponds very nearly with the average nominal serviceable life-period of the companies' works and plant considered as a whole, Appendix, Table A 3.

The Author would submit, therefore, that in these results, obtained from an analysis of 30 years' working expenditure, sufficient evidence is afforded to justify the conclusion, which it is one of the chief objects of this Paper to demonstrate, that in this large annual expenditure on "Maintenance" (amounting in the aggregate to over 6⅔ millions sterling during the 30 years, and exceeding the amount of the entire capital of the companies at the commencement of that period), adequate provision has been made and continues to be made for all renewals, whether partial or entire, of the various works, plant and machinery; and, having regard to this and to the necessary continuity of the operations, there is no need, any more than there is in the analogous case of a railway, for the provision of sinking-funds either for the recouping of the capital invested in these undertakings, or for the renewal of the operating works and plant which have become worn out.

In the early days of railways, renewal- and sinking-funds were resorted to in order to make provision out of revenue for the renewal, at distant periods in the future, of the worn-out permanent-way and rolling-stock. The rapid, and at that time unlooked-for, destructive effects of the wear and tear of the traffic, however, soon led to renewals of the shortest-lived portions of the permanent-way and rolling-stock, but when the average serviceable life-periods of the permanent-way and rolling-stock, each considered as a whole, had been reached, it became evident that on a given length of line, with a given amount of traffic,

there was a degree of constancy in the annual maintenance expenditure per mile of railway or per train-mile in the one case, and per engine or vehicle or per train-mile in the other; and, inasmuch as any increase of traffic, with its attendant additional cost in maintenance, was as a rule attended with a proportionate increase of revenue, the ratios of expenses to receipts practically remained the same, and consequently there was no need for any renewal- or sinking-funds, which have long since been abolished on railways. In short, it soon became obvious that, in all undertakings for the conveyance of traffic, whether in water or any other commodity, where no time-limit for its cessation is foreseen, the working expenditure must include the cost of the repairs and renewals of the appliances used, which in these cases are subject to constant wear and tear.

A remarkable instance of this constancy in the annual maintenance and renewal expenditure which recently has come under the notice of the Author is afforded in the cost of the repairs and renewals of the London and North Western Railway locomotive-stock during the last 30 years. This stock, which now comprises nearly 3,000 engines[1] of different types, ages, and powers, has, during the period under review, nearly doubled in number, weight, and tractive power of the engines; the total expenditure on maintenance and renewals has amounted to £11,375,000, the aggregate mileage run being 1,091 million train-miles, giving an average of 462,198 miles per engine, Appendix, Table D. The maintenance and renewal expenditure per engine during the period in question has been on an average £4,897 7*s.* 2*d.*, or £163 5*s.* 0*d.* per engine per annum. With regard to the constancy of this annual expenditure, it should be explained that the calculated total maintenance expenditure on each engine during this period of 30 years (the estimated average life-period of the side-frames and other longest-lived portions of an engine), based on the observed average serviceable life-periods of all the different parts of one of this Company's standard types of engine, as furnished to the Author with other valuable data[2] by Mr. F. W. Webb, M. Inst. C.E., was £4,890 5*s.* 0*d.*, and the average annual expenditure per engine £163,[3] a very close approximation to the actual expenditure during that long period. It is equally remarkable and noteworthy that the amounts expended on

[1] No. 2986 Board of Trade Returns, 1900.

[2] Minutes of Proceedings Inst. C.E., vol. xxx. p. 136.

[3] Molesworth's Pocket-book, 24th edition, p. 265.

labour and on materials should have continued to be practically equal during this long period, notwithstanding the large reduction which has occurred in the price of materials, accompanied by a very appreciable increase in the cost of labour. The explanation no doubt is to be found in the greater quantity of cheaper material used in the construction of the more powerful types of engines now in use, and, on the other hand, in the large economies resulting from improvements in construction, and the employment of labour-saving appliances, counteracting the effects of the enhanced cost of labour.

Apart from the question of the sufficiency of the maintenance expenditure as a provision for the current renewals of the Water Companies' works and plant, there is in the detailed statements of each company's maintenance expenditure (Appendix, Tables B), a great deal in relation to the subject deserving of attention, more especially with regard to the considerable differences observable in the cost, per million gallons, of some of the items of maintenance expenses, which do not appear to be entirely accounted for by the varying circumstances and conditions of the operations in the particular districts served. An instance is afforded in the case of the Chelsea Company, to which allusion has already been made, where all the items of expenditure, with the exception of storage and salaries, have continued throughout this long period to be much below the average, while the "Salaries" item has continued exceptionally high. In the case of the Kent Company, although the pumping expenditure, from the exceedingly heavy character of its pumping operations, is in excess of the average, its maintenance expenses are, and have continued to be, the lowest of all the companies, with the exception of the Chelsea Company, which is partly accounted for by the absence of any expenditure on filtration, this not being required.

Notwithstanding the considerable difference observable in the items of cost of maintenance of some of the companies, there is singularly little variation either in the amounts or percentages of the maintenance expenses per million gallons in the aggregate, strongly confirming the advisability of dealing with the maintenance of these companies as a whole. This is especially noticeable in the two principal items of "Pumping" and "Distribution," which, as already stated, constitute nearly three-fourths of the maintenance expenditure.

From the Appendix, Tables B, it will be seen that while on the average there has been an appreciable increase in all the items of maintenance expenditure per million gallons, excepting storage,

there is now a considerably less proportion of the expenditure devoted to the items of "Pumping" and "Salaries," and a larger amount spent upon distribution.

In conclusion, it should be stated that where the Author has drawn attention to any item of maintenance expenditure of a particular company exceptionally divergent from the average, it has been done solely with the view of ascertaining if possible from the company's representatives the special circumstances, not otherwise apparent, to which no doubt this is attributable; and with regard to the question of a sinking fund, the Author feels that, in submitting his views on the subject, greater prominence ought perhaps to have been given to the fact that much special attention has recently been given to it in the Report of the Royal Commission, in connection with what is known as the City Chamberlain's Sinking Fund of the London Water Companies, and that as there is moreover a difference of opinion in regard to the subject, there would in his opinion appear to be all the more reason for its being submitted to the consideration of those who are most competent to deal with it.

The Paper is accompanied by one drawing and nine tracings, from which Plates 8 and 9 have been prepared; and by the Tables given in the following Appendix.

APPENDIX.

TABLES A.—CAPITAL RAISED AND ANNUAL EXPENDITURE ON MAINTENANCE, &c., OF WORKS, PLANT, &c.

TABLE A 1.—1871.

—	1	2	3	4	5	6	7	8	9	10	11
	Water Supplied.	Storage.	Distribution.	Pumping.	Filtration	Salaries.	Annual Maintenance Expenses.	Total Capital Raised.	Capital Raised per Million Gallons.	Annual Cost of Maintenance and Renewals.	Average Period to recoup Capital.
	Million Gallons.	£	£	£	£	£	£	£	£	Per Million Gallons. £	Col. 10 / Col. 11 Years.
Chelsea . . (Fig. 5, Plate 9)	3,060·95	[1]	3,938	7,115	944	[1]	11,997	828,692	270·73	2·83	95·72
East London („ 6, „)	7,458·59	2,504	8,417	8,120	1,649	5,338	26,028	1,727,560	231·63	2·57	90·76
Grand Junction . . („ 7, „)	4,071·95	[1]	3,776	12,346	1,142	5,660	22,924	1,006,090	247·08	2·60	95·11
Kent . . . („ 8, „)	2,581·16	61	2,591	7,405	..	2,211	12,268	475,997	184·41	2·55	72·21
Lambeth . („ 9, „)	3,816·50	3,372	4,708	10,378	1,089	3,548	23,095	985,467	258·21	3·71	69·60
New River . („ 10, „)	8,660·48	6,663	24,782	13,922	2,438	4,656	52,461	2,651,975	306·21	4·54	67·41
Southwark and Vauxhall („ 11, „)	6,012·42	3,604	[1]	21,078	[1]	2,494	27,176	1,455,391	242·07	2·50	96·88
West Middlesex . . („ 12, „)	3,422·84	[1]	1,790	7,634	[1]	10,789	20,213	878,731	256·73	3·90	65·84
Totals . („ 13, „)	39,084·89	16,201	50,002	87,998	7,262	34,696	196,162	10,009,903	256·11	3·26	78·47
Per million gallons	..	0·41	1·28	2·25	0·19	0·89	5·02				
Percentages	..	8·26	5·49	44·86	3·70	17·69	100·00				

[1] These items not given separately in this year.

TABLES A.—CAPITAL RAISED, AND ANNUAL EXPENDITURE ON MAINTENANCE, &c., OF WORKS, PLANT, &c.—*continued.*

TABLE A 2.—30 YEARS' MAINTENANCE AND RENEWAL EXPENDITURE (1871 TO 1900 INCLUSIVE).

—	1	2	3	4	5	6	7	8	9	10	11	12
	Water Supplied.	Storage.	Distribution	A Pumping.	Filtration	Salaries.	Total Maintenance Expenses.	B Annual Maintenance and Renewal Expenses.	Total Capital Raised.	Capital Raised per Million Gallons.	Annual Cost of Maintenance and Renewals.	Average Period to recoup Capital.
	Million Gallons.	£	£	£	£	£	£	£	£ Averages.	£ Averages.	Per Million Gallons. £	Col. 10 / Col. 11 Years.
Chelsea . . .	107,628·38	49,432	132,167	214,997	29,401	132,249	558,246	13,389	1,153,902	321·64	3·74	86·00
East London .	386,093·11	183,946	385,621	570 929	136,065	346,535	1,623,096	39,830	2,259,694	175·58	3·09	56·82
Grand Junction	169,602·28	21,966	336,298	480,726	61,570	204,537	1,105,097	20,812	1,358,751	240·35	3·68	65·32
Kent	122,649·21	9,095	134,304	416,927	..	114,271	674,597	12,063	779,231	190·60	2·95	64·60
Lambeth . .	193,962·65	63,638	409,620	734,917	55,948	160,235	1,424,358	29,106	1,564,687	242·04	4·50	53·76
New River . .	337,393·82	241,456	828,119	736,289	97,957	304,498	2,208,319	55,203	3,280,947	291·74	4·91	59·41
Southwark and Vauxhall . .	268,164·14	31,718	531,612	710,796	107,610	207,699	1,589,435	29,288	2,119,348	237·09	3·28	72·36
West Middlesex	160,224·63	42,364	206,386	543,265	78,783	239,670	1,110,468	23,434	1,223,691	229·13	4·39	52·22
Totals . .	1,745,718·22	643,615	2,964,127	4,408,846	567,334	1,709,694	10,293,616	223,125	13,440,251	236·70	3·83	61·80
Annual average	58,190·60	21,454	98,804	146,961	18,911	56,990	343,121					
Per million gallons . .	..	0·37	1·70	2·53	[1] 0·32	0·98	5·90					
Percentages . .	..	6·25	28·80	42·83	5·51	16·61	100·00					

A—Including water traffic expenses.
B—Excluding " " "

[1] Excluding Kent water, 0·35.

TABLES A.—CAPITAL RAISED, AND ANNUAL EXPENDITURE ON MAINTENANCE, &c., OF WORKS, PLANT, &c.—*continued.*

TABLE A 3.—AVERAGES OF 1898, 1899 AND 1900.

—	1	2	3	4	5	6	7	8	9	10	11	12
	Water Supplied.	Storage.	Distribution.	Pumping.	Filtration	Salaries.	Total Maintenance Expenses.	Annual Maintenance and Renewal Expenses.	Total Capital Raised.	Capital Raised per Million Gallons.	Annual Cost of Maintenance and Renewals.	Average Period to recoup Capital.
	Million Gallons.	£	£	£	£	£	£	£	£	£	Per Million Gallons. £	Col. 10 / Col. 11 Years.
Chelsea . . .	4,582·29	2,282	4,760	7,996	1,616	5,903	22,557	16,509	1,318,253	287·70	3·61	79·86
East London .	14,984·66	7,725	20,831	32,374	6,837	16,614	84,381	60,101	3,135,556	209·25	4·02	52·05
Grand Junction	7,291·51	1,411	14,805	22,488	8,096	10,337	52,137	29,649	1,605,083	220·13	4·06	54·14
Kent	6,297·77	405	7,061	25,441	..	6,295	39,202	20,121	976,667	155·08	3·19	48·54
Lambeth . .	9,479·21	2,340	19,162	34,133	2,860	5,490	63,985	38,385	2,016,661	212·75	4·04	52·54
New River . .	14,013·69	18,323	28,430	43,355	3,842	12,853	106,803	74,287	3,788,293	269·97	5·30	50·93
Southwark and Vauxhall . .	11,901·08	1,377	24,786	33,574	4,485	9,053	73,276	39,701	3,037,585	255·24	3·84	76·66
West Middlesex	7,822·62	2,255	9,596	25,692	3,373	10,557	51,473	32,204	1,668,202	213·25	4·12	51·80
Totals . .	76,372·83	36,118	129,431	225,053	26,109	77,102	493,814	310,957	17,541,300	229·68	4·07	56·41
Per million gallons . .	..	0·47	1·70	2·95	[1]0·37	1·01	6·47	4·07	-			
Percentages . .	..	7·31	26·21	45·58	5·29	15·61	100·00	..				

[1] Kent water omitted.

TABLES B.—ANNUAL EXPENDITURE PER MILLION GALLONS.

—	Chelsea.	East London.	Grand Junction.	Kent.	Lambeth.	New River.	Southwark and Vauxhall.	West Middlesex.	Average Expenditure per Million Gallons.	Percentages; Aggregate Expenditure.
	£	£	£	£	£	£	£	£	£	Per Cent.
TABLE B 1—1871.										
Storage	[1]	−0·34	[1]	⊖0·02	⊕0·88	+0·77	+0·59	[1]	0·41	8·26
Distribution	+1·29	−1·13	−0·93	−1·00	−1·23	⊕2·86	[1]	⊖0·52	1·28	25·49
Pumping	+2·32	⊖1·09	+3·03	+2·87	+2·72	−1·61	⊕3·51	−2·23	2·25	44·86
Filtration	+0·31	+0·22	+0·28	..	+0·29	+0·28	[1]	[1]	0·19[2]	3·70
Salaries	[1]	−0·71	+1·39	−0·86	+0·93	−0·61	⊖0·41	⊕3·16	0·89	17·69
Totals	−3·92	⊖3·49	+5·62	−4·75	+6·05	⊕6·13	−4·51	+5·91	5·02	100·00
TABLE B 2.—1871 TO 1900 (INCLUSIVE). AVERAGE EXPENDITURE.										
Storage	+0·46	+0·48	−0·13	⊖0·07	−0·33	⊕0·72	−0·12	−0·26	0·37	6·25
Distribution	−1·23	⊖1·00	−1·98	−1·10	+2·11	⊕2·45	+1·99	−1·29	1·70	28·28
Pumping	⊖2·00	−1·48	+2·84	+3·40	⊕3·79	−2·18	+2·65	+3·39	2·53	43·35
Filtration	⊖0·27	+0·35	+0·36	..	−0·29	−0·29	⊖0·40	+0·49	0·32[3]	5·51
Salaries	⊖1·23	−0·90	+1·21	−0·93	−0·83	−0·90	⊖0·77	+1·50	0·98	16·61
Totals	−5·19	⊖4·21	+6·52	−5·50	⊕7·35	+6·54	+5·93	+6·93	5·90	100·00
TABLE B 3.—PERCENTAGES.										
Storage	+ 8·85	⊕11·33	− 1·99	⊖ 1·35	− 4·47	+10·93	− 1·99	− 3·81	6·25	
Distribution	−23·68	−23·76	+30·43	−19·91	+28·76	⊕37·50	+33·49	−18·59	28·80	
Pumping	−38·51	−35·18	+43·50	⊕61·80	+51·59	⊖33·34	+44·69	+48·92	42·83	
Filtration	− 5·27	⊕ 8·38	+ 5·57	..	⊖ 3·93	− 4·44	+ 6·77	+ 7·10	5·51	
Salaries	⊕23·69	+21·35	+18·51	+16·94	−11·25	−13·79	−13·06	+21·58	16·61	
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	

TABLE B 4.—1898, 1899 AND 1900 (AVERAGE EXPENDITURE).

Storage	+0·50	+0·52	−0·19	⊖0·06	−0·24	⊕1·81	−0·12	−0·29	0·47	7·34
Distribution	⊖1·04	−1·39	+2·03	−1·12	+2·02	+1·92	⊕2·08	−1·23	1·67	25·99
Pumping	⊖1·75	−2·16	+3·08	⊕4·04	+3·60	+3·09	−2·82	+3·28	2·95	45·71
Filtration	+0·35	⊕0·46	+0·43	..	−0·30	⊖0·27	+0·38	+0·43	0·34[4]	5·30
Salaries	+1·29	+1·11	⊕1·42	−1·00	−0·58	−0·92	−0·76	+1·35	1·01	15·66
Totals	⊖4·93	−5·64	+7·15	−6·22	+6·74	⊕7·51	−6·16	+6·58	6·44	100·00

TABLE B5.—PERCENTAGES.

Storage	+10·12	+ 9·16	− 2·71	⊖ 1·03	− 3·66	⊕17·40	− 1·88	− 4·38	7·34	
Distribution	−21·10	−24·69	+28·40	−18·01	+29·94	−25·59	+33·83	−18·64	25·99	
Pumping	−35·45	−38·37	−43·13	⊕64·90	+53·35	−41·16	+45·82	+49·91	45·71	
Filtration	+ 7·16	+ 8·10	+ 5·94	..	− 4·47	− 3·65	+ 6·12	+ 6·56	5·30	
Salaries	⊕26·17	+19·68	+19·82	+16·06	⊖ 8·58	−12·20	−12·35	+20·51	15·66	
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	

TABLE B 6.—1900.

Storage	+0·62	−0·49	−0·14	⊖0·05	−0·22	⊕1·49	−0·18	−0·20	0·50	7·40
Distribution	⊖0·97	−1·09	+1·79	−0·99	+2·00	⊕2·04	+1·87	−1·20	1·56	23·29
Pumping	−2·04	−2·51	−3·25	⊕5·04	+4·03	−3·09	+3·38	+3·76	3·32	49·65
Filtration	−0·28	+0·36	⊖0·51	..	−0·30	⊖0·25	+0·38	+0·45	0·32[5]	4·83
Salaries	+1·28	−0·98	⊕1·47	−0·98	⊖0·56	−0·89	−0·81	+1·39	0·99	14·83
Totals	−5·19	−5·48	+7·16	+7·06	+7·11	⊕7·76	−6·57	+7·00	6·69	100·00

TABLE B7.—PERCENTAGES.

Storage	+11·94	+ 8·95	− 2·02	⊖ 0·73	− 3 06	⊕19·22	− 1·97	− 2·80	7 40	
Distribution	−18·72	−20·03	+24·96	⊖14·00	+28·08	+26·29	⊕28·50	−17·16	23·29	
Pumping	⊖39·19	−46·22	−45·45	⊖71·35	+56·73	−39·83	+51·48	+53·78	49·65	
Filtration	+ 5·45	+ 6·69	+ 7·07	..	− 4·24	− 3·22	+ 5·73	+ 0·42	4·83	
Salaries	+24·70	+18·11	+20·50	−13·92	− 7·89	−11·44	−12·32	+19·84	14·83	
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	

NOTE.—Above average +; below average −; maximum ⊕; minimum ⊖.

Pumping in all these cases includes the water traffic expenses; exclusively in the case of the Grand Junction and Southwark and Vauxhall.

[1] Not shown separately. [2] £0·27 omitting Kent. [3] £0·35 excluding Kent. [4] £0·37 excluding Kent. [5] £0·37 excluding Kent.

TABLE C.—AVERAGES OF THE "LAST THREE PRECEDING YEARS," 1898, 1899, 1900.

—	Water Supplied.	Storage.	Distribution.	Pumping.	Filtration.	Salaries.	Totals Maintenance and Renewals.	Total Working Expenditure.	Ratio of Expenditure to Receipts. Maintenance of Works.	Ratio of Expenditure to Receipts. Total Expenditure.	Capital Raised.	Capital Expended.
Chelsea.	Million Galls.	£	£	£	£	£	£	£	Per Cent.	Per Cent.	£	£
1898	4,372,817	1,809	4,794	6,924	1,731	5,807	21,065	52,092	..	..	1,317,580	1,306,639
1899	4,622,128	2,092	4,869	7,395	1,767	5,809	21,932	53,590	..	..	1,318,590	1,327,225
1900	4,751,910	2,945	4,618	9,669	1,349	6,092	24,673	58,420	..	..	1,318,590	1,379,670
Average	4,582,285	2,282	4,760	7,996	1,616	5,903	22,557	54,701	13·69	33·19	1,318,253	1,337,845
East London.												
1898	14,284,734	6,174	25,867	26,250	9,012	16,752	84,055	179,967	..	..	3,015,300	3,090,761
1899	15,290,272	9,520	19,895	32,244	5,907	17,957	85,523	199,871	..	..	3,035,900	3,299,340
1900	15,378,987	7,481	16,732	38,627	5,593	15,133	83,566	173,538	..	..	3,355,469	3,488,259
Average	14,984,664	7,725	20,831	32,374	6,837	16,614	84,381	184,459	23·68	51·77	3,135,556	3,292,787
Grand Junction.												
1898	7,135,391	2,060	16,429	19,828	2,711	9,744	50,772	101,207	..	..	1,580,000	1,795,836
1899	7,413,551	1,114	14,890	23,794	2,865	10,515	53,178	106,606	..	..	1,580,000	1,822,485
1900	7,325,666	1,058	13,095	23,842	3,711	10,752	52,458	109,657	..	..	1,655,250	1,841,475
Average	7,291,506	1,411	14,805	22,488	3,096	10,337	52,187	105,823	23·58	47·86	1,605,083	1,819,765
Kent.												
1898	5,967,543	441	7,861	20,099		6,225	34,626	64,884	..	..	950,000	1,022,332
1899	6,372,478	436	6,839	23,177		6,210	36,662	67,628	..	..	990,000	1,036,290
1900	6,553,300	337	6,483	33,047		6,450	46,317	76,937	..	..	990,000	1,061,668
Average	6,297,774	405	7,061	25,441		6,295	39,202	69,816	20·73	36·92	976,667	1,040,097

Lambeth.												
1898	9,269,432	2,676	18,573	30,852	2,833	5,035	59,969	111,207	..	..	1,950,000	1,971,120
1899	9,525,829	2,249	19,680	32,679	2,838	6,030	63,476	117,214	..	..	1,981,100	2,052,153
1900	9,612,373	2,096	19,234	38,867	2,908	5,406	68,511	126,794	..	..	2,118,883	2,144,153
Average	9,479,211	2,340	19,162	34,133	2,860	5,490	63,985	118,405	22·11	40·91	2,016,661	2,055,809
New River.												
1898	13,719,506	18,758	27,971	44,182	4.227	13,239	108,377	244,769	..	..	3,639,958	3,770,107
1899	13,939,199	14,787	28,013	41,490	3,711	12,570	100,571	249,370	..	..	3,759,958	3,845,487
1900	14,382,371	21,425	29,306	44,393	3,588	12,750	111,462	262,147	..	..	3,949,963	3,932,101
Average	14,013,692	18,323	28,430	43,355	3,842	12,853	106,803	252,095	17·84	42·70	3,783,293	3,849,231
Southwark and Vauxhall.												
1898	11,836,615	1,216	29,974	27,862	4,413	8,969	72,434	126,774	..	..	2,837,585	3,030,958
1899	12,105,897	1,395	22,361	33,081	4,614	8,661	70,112	129,547	..	..	3,087,585	3,164,282
1900	11,760,727	1,519	22,023	39,780	4,429	9,530	77,281	137,067	..	..	3,187,585	3,265,212
Average	11,901,080	1,377	24,786	33,574	4,485	9,053	73,276	131,129	26·29	47·05	3,037,585	3,155,484
West Middlesex.												
1898	7,786,670	3,527	8,994	24,065	3,360	10,116	50,082	112,594	..	..	1,555,066	1,676,678
1899	7,887,324	1,708	10,443	23,696	3,240	10,743	49,830	119,194	..	..	1,655,066	1,759,033
1900	7,793,872	1,530	9,351	29,314	3,500	10,813	54,508	134,140	..	..	1,794,474	1,890,334
Average	7,822,622	2,255	9,596	25,692	3,373	10,557	51,473	121,976	20·21	47·88	1,668,202	1,775,348
Totals.												
1898	74,372,618	36,661	140,463	200,062	28,307	75,887	481,380	998,494	..	..	16,845,489	17,663,931
1899	77,156,678	33,301	126,990	217,556	24,942	78,495	481,284	1,043,020	..	..	17,408,199	18,306,295
1900	77,589.206	38,391	120,842	257,539	25,078	76,926	518,776	1,078,609	..	..	18,370,214	19,002,872
Average	76,372,834	36,118	129,432	225,052	26,109	77,103	493,813	1,038,405	21·00	44·29	17,541,301	18,324,033

D.—London and North Western Railway. Locomotive Repairs and Renewals during a period of 30 Years (1869–1898 inclusive).

Year.	Number of Engines.	Wages.	Per Engine.	Materials.	Per Engine.	Total Wages and Materials.	Per Engine.	Total Train-Miles.	Train Miles per Engine.	Total Expenses per Train-Mile.
		£	£	£	£	£	£			Pence.
1869	1,539	168,706	109·62	176,956	114·98	345,662	224·60	23,279,060	15,127	3·5636
1870	1,559	171,143	109·78	155,608	99·81	326,751	209·59	25,037,527	16,060	3·1321
1871	1,619	156,448	96·63	154,430	95·38	310,878	192·01	26,507,002	16,372	2·8147
1872	1,791	168,207	93·92	158,452	88·47	326,659	182·39	28,835,016	16,101	2·7188
1873	2,032	189,712	93·36	211,517	104·10	401,229	197·46	30,123,750	14,825	3·1966
1874	2,085	189,917	91·09	202,925	97·33	392,842	188·42	30,474,401	14,616	3·0939
1875	2,157	189,506	87·86	203,367	94·28	392,873	182·14	31,748,606	14,719	2·9698
1876	2,196	173,934	79·20	196,986	89·70	370,920	168·90	32,323,759	14,719	2·7540
1877	2,233	181,909	81·46	180,348	80·77	362,257	162·23	32,701,680	14,645	2·6586
1878	2,247	186,099	82·82	164,858	73·37	350,957	156·19	32,498,113	14,463	2·5918
1879	2,246	174,047	77·49	150,270	66·91	324,317	144·40	32,517,988	14,478	2·3936
1880	2,266	188,770	83·30	143,608	63·38	332,378	146·68	34,911,787	15,406	2·2850
1881	2,315	189,822	82·40	146,644	63·35	336,466	145·35	36,188,478	15,632	2·2315
1882	2,377	170,547	71·75	162,535	68·38	333,082	140·13	36,780,454	15,473	2·1735
1883	2,419	180,480	74·61	187,372	77·46	367,852	152·07	38,096,778	15,749	2·3173
1884	2,462	178,602	72·55	201,871	81·99	380,473	154·54	37,948,865	15,414	2·4062

1885	2,490	170,339	68·41	196,842	78·85	366,681	147·26	37,974,227	15,251	2·3174
1886	2,523	173,629	68·82	201,409	79·83	375,038	148·65	37,625,328	14,913	2·3928
1887	2,543	190,068	74·74	212,244	83·46	402,312	158·20	38,087,184	14,977	2·5351
1888	2,547	189,189	74·28	203,208	79·79	392,397	154·07	38,641,005	15,171	2·4373
1889	2,551	196,085	76·87	218,214	85·54	414,299	162·41	40,543,888	15,894	2·4536
1890	2,592	198,161	76·45	204,159	78·77	402,320	155·22	41,899,410	16,165	2·3045
1891	2,621	192,411	73·41	209,496	79·93	401,907	153·34	42,494,389	16,213	2·2699
1892	2,671	193,488	72·44	213,448	79·92	406,936	152·36	43,236,699	16,188	2·2589
1893	2,717	184,335	67·85	217,553	80·07	401,888	147·92	41,131,988	15,138	2·3450
1894	2,741	188,903	68·92	209,485	76·43	398,388	145·35	41,466,847	15,121	2·3058
1895	2,761	194,544	70·46	216,033	78·25	410,577	148·71	41,655,965	15,087	2·3655
1896	2,780	205,611	73·96	228,537	82·21	434,148	156·17	43,303,238	15,577	2·4062
1897	2,812	203,315	72·31	240,320	85·46	443,635	157·77	45,486,774	16,176	2·3407
1898	2,878	218,649	75·97	249,965	86·86	468,614	162·83	47,548,652	16,521	2·3653
Totals and Average	2,359	5,556,571	2402·33	5,818,160	2,495·03	11,374,741	4,897·36	1,091,070,333	462,198	76·4984
Average per Engine	..	..	80·08	..	83·17	..	163·25	..	15,107	2·5499
		By calculation (*vide* Molesworth, p. 265)				. . . .	4,890·50			
			”	”	”	. . . .	163·00			

TABLE E.—THE EIGHT LONDON WATERWORKS (1871–1899 INCLUSIVE).

—	Water Supplied.	Storage Reservoir.	Distribution Mains, etc.	Pumping.	Filtration.	Salaries.	Totals.
	1 = 1,000 Galls.	£	£	£	£	£	£
1871	39,084,874	16,204	50,002	87,998	7,262	34,696	196,162
1872	39,505,076	14,026	51,803	119,105	13,141	36,618	234,693
1873	41,318,956	15,604	54,778	140,422	12,598	37,502	260,904
1874	42,477,367	14,641	61,964	129,604	12,861	38,806	257,876
1875	42,617,151	12,551	62,074	128,189	12,144	39,204	254,162
1876	42,952,381	16,323	66,379	139,234	16,238	42,031	280,205
1877	44,115,535	17,964	68,468	133,333	[1]24,828	45,374	289,967
1878	47,325,118	22,464	78,706	124,854	14,630	49,058	289,712
1879	49,139,279	21,784	94,368	118,041	15,613	50,122	299,928
1880	51,967,036	21,334	93,861	122,539	14,782	51,751	304,267
1881	54,319,443	18,771	92,785	125,295	15,518	54,454	306,823
1882	51,294,659	21,152	82,796	119,160	15,869	54,920	293,897
1883	53,586,798	20,894	87,313	120,080	15,714	54,615	298,616
1884	56,270,648	16,721	82,237	131,729	15,588	57,295	303,570
1885	56,958,591	18,672	95,930	131,134	14,644	56,981	317,361
1886	59,196,421	16,290	96,171	134,454	15,612	56,574	319,101
1887	59,731,849	17,866	97,461	135,473	[2]28,380	58,215	337,395
1888	59,357,331	19,299	87,399	129,805	[3]26,433	59,076	322,012
1889	61,670,436	18,978	91,566	148,510	20,881	61,428	341,363
1890	64,730,158	18,584	94,075	161,546	17,092	61,478	352,775
1891	66,923,126	22,533	91,144	172,766	17,920	63,001	367,364
1892	68,505,176	24,354	101,118	161,525	19,848	62,797	369,642
1893	70,112,469	25,724	104,110	170,500	[4]27,804	65,846	393,984
1894	69,647,309	24,171	141,794	168,002	23,240	68,492	425,699
1895	77,380,836	23,198	[1]227,783	183,994	21,339	71,229	[5]527,543
1896	72,562,639	25,310	143,876	177,462	22,669	72,859	442,176
1897	73,855,061	29,848	126,563	173,242	26,360	73,962	429,976
1898	74,372,618	36,661	137,961	200,062	28,307	75,887	478,878
1899	77,156,679	33,301	125,061	217,556	24,942	78,495	479,355
1900	77,589,206	38,391	120,842	257,539	25,078	76,926	518,775
Total 30 years	1,745,719,221	643,613	2,910,388	4,463,153	567,335	1,709,692	10,294,181
	Percentages	6·25	28·24	43·38	5·51	16·62	100·00

[1] Southwark and Vauxhall, £13,764. [2] West Middlesex, £13,781.
[3] West Middlesex, £11,331. [4] East London, £10,004. [5] Severe frost.

TABLE F.—POPULATION OF LONDON, REGISTRAR-GENERAL'S DISTRICT, AND OF GREATER AND WATER LONDON, 1841–1891. ESTIMATED POPULATION 1901.

Decade.	Registrar-General's District. 74,427 Acres of Water.		Greater and Water London. 535,734 Acres = 837 Square Miles.			Remarks.
	Population.	Decade Rate Increase.	Population.	Increase per Decade.	Rate of Increase.	
1841	1,948,417	17·73	2,235,344	..	..	As no particulars of the population of Water London are given prior to 1881, it is here omitted in calculating the average rate of increase, and added afterwards in estimating the 1901 population.
1851	2,362,236	21·24	2,680,735	445,391	19·93	
1861	2,803,989	18·70	3,222,720	541,985	20·22	
1871	3,254,260	16·06	3,885,641	662,921	20·57	
1881	3,816,481	17·26	4,766,661[2]	881,020	22·67	
1891	4,211,743	10·36	5,633,332[3]	886,671	18·18	
Average rate per decade . . .		16·73	..	..	20·31	
Average rate per decrement in rate of increase per decade . .		14·63	..	..	1·59	

ESTIMATED POPULATION IN 1901; BASED ON AVERAGE OF LAST 50 YEARS. DECREMENTAL RATE OF INCREASE.

1891	4,211,743	16·73[1]	5,709,373[4]	..	20·31[1]	Average 50 years.
1901	4,813,170	14·28	6,850,700[4]	1,141,327	19·99	Decremental rate 15·9 per cent.

NOTE.—The preliminary Census Returns for 1901 show that the population of Greater London in 1891 and 1901 was as follows—

——	——	Extra Water London.	Total Greater and Water London.
Census 1901 Greater London . .	6,604,287	105,460[1]	6,709,747
„ 1891 „ „ . .	5,633,332	76,041	5,709,373
Decennial increase	970,955	29,419	1,000,374

[1] Estimated at average rate preceding decade.
[2] Population of Water London omitted 1881 . . . 63,543.
[3] „ „ „ „ 1891 . . . 76,041.
[4] „ „ „ included.

(*Paper No. 3308.*)

"The Calcutta Waterworks."

By Arthur Peirce, Assoc. M. Inst. C.E.

Calcutta, the "City of Palaces," the capital of the Indian Empire, is situated in latitude 22° 30′ north, and longitude 88° 20′ east. The town proper, including the Maidan and Fort William, covers an area of 7½ square miles, having a length, from north to south, of about 5 miles, and an average width, from east to west, of a little over 1½ mile. Calcutta is built along the right bank of the River Húgli, on the low-lying ground of the great Gangetic Delta, Fig. 1, Plate 10. The surrounding country is extremely flat, and the 100 feet contour-line is at its nearest point 100 miles distant from the town.

The average rainfall during the years 1870–1895 amounted to 61·49 inches, the highest rainfall in any one day during that period being 8·46 inches, on 20 June 1893. This record has since been greatly exceeded; for the two days, 20 and 21 September 1900, the rainfall was 14·53 inches and 10·83 inches respectively, and for the week ending 25 September the total rainfall was 40·35 inches. Practically the whole of the rain falls during the monsoon in the months of June, July, August, and September. The average monthly maximum shade-temperature may be taken as ranging between 76·1° F. and 95·4° F., and the minimum temperature between 55·4° F. and 78·8° F., the highest and lowest temperatures of the year being about 107° F. and 44·2° F. respectively. The degree of humidity, complete saturation being 100, varies between 66 and 89.

History of the Water-Supply.—Previous to the introduction of the scheme for the supply of filtered water to the town, Calcutta depended for its water-supply upon the River Húgli, and upon tanks or reservoirs excavated in various quarters of the town, the tanks being wholly dependent upon the rainfall. An improvement in the distribution, if not in the nature, of the supply was effected

in 1820 by the erection of a small pumping-plant on the banks of the river, which distributed water directly from the river to a limited area by means of open brick aqueducts laid along the streets, from which water could be drawn and contiguous tanks could be replenished. The pumping-plant was subsequently enlarged, in 1835, when a condensing engine was added. The necessity for an improved water-supply appears to have been discussed for many years, and especially upon the commencement of drainage-works, in 1859, but owing to financial and other reasons it was not until the year 1862 that the governing body of the town, the Justices of the Peace, adopted a scheme prepared by their engineer, the late Mr. W. Clark, M. Inst. C.E. The scheme, subsequently enlarged and modified, provided for the filtering and distribution through pipes of 3 million to 4½ million gallons of water per day, at an estimated cost of 11 to 13½ lakhs of rupees (at that time equal to £110,000 to £135,000).

Filtered Water-Supply.

Original Works.—The construction of the original works was commenced in 1866–1867. They were designed to supply 6,000,000 gallons of filtered water per day, to a population estimated at 400,000, or an average of 15 gallons per head per day. The cost of the project was estimated at 57,00,000 rupees, or £570,000. The actual cost of the work appears to have been the following:—

	Rupees.
Land	2,20,000
Pumping-station, machinery, etc.	41,58,000
Pipes	15,25,000
Engineering expenses	2,90,000
Interest on loan during construction	4,00,000
Total	65,93,000

or about £660,000.

The contract for the works was undertaken by Messrs. Brassey, Wythes and Aird.

Intake-works were constructed on the river-bank at Palta, about 14 miles above Calcutta, and practically beyond the influence of the brackish water brought in by the tide, Fig. 10, Plate 10. Water is pumped from the river by three 50-HP. beam-engines, into six masonry settling-tanks having a total capacity of 24¼ million gallons. From these tanks the water gravitates, after settling, on to the filter-beds, twelve in number, which have a

collective area of 240,000 square feet. After filtration the water is collected in a central well, and gravitates through a 42-inch cast-iron pipe, having an average fall of about 1 foot to the mile, to a second station at Tallah, some 12½ miles distant, and near the northern boundary of Calcutta. At Tallah the water is received into a covered reservoir of 1 million gallons capacity, from which it is raised by pumping-machinery and distributed, one portion of the supply meeting the needs of the population in the northern section of the town, whilst the remainder is delivered into an underground reservoir of 6¼ million gallons capacity, in the heart of the town, at Wellington Square, from which pumping-machinery completes the distribution. The distribution is effected by pumping directly into the mains, without intervention of raised reservoirs or stand-pipes.

New Works.—The growth of the population, together with the extension of the boundaries in 1888 by the inclusion of the southern suburbs in the town area, led to a largely increased demand upon the works as originally carried out, and it was accordingly decided to augment the supply considerably. A new pumping-station was erected at Palta, about ½ mile distant from the old station. Three 75-HP. pumping-engines were installed, and ample provision for settling purposes was obtained by the construction of four large "kutcha" or earthen settling-tanks, two of 2,060 feet in length by 230 feet in width, and two of 2,060 feet by 355 feet, the whole having a total useful capacity of 82,750,000 gallons. Twenty-four additional filter-beds were also constructed, each 200 feet by 100 feet, increasing the filter area by 480,000 square feet. To convey the increased supply of water to Calcutta, a new 48-inch cast-iron pipe, 66,000 feet in length, was laid between Palta and Tallah pumping-stations. The works at the receiving-station at Tallah were strengthened by the addition of two new pumping-engines, whilst the reservoir accommodation was increased from 1 million gallons to 3 million gallons. An additional pumping-engine was erected at Wellington Square pumping-station, and a new station was erected at Halliday Street, where four beam-engines were fixed, and an underground reservoir was constructed, of 4,000,000 gallons capacity. For the supply of the southern suburbs a new pumping-station was built at Bhowanipur and was fitted with two triple-expansion Worthington engines, and provided with an underground reservoir of nearly 3,000,000 gallons capacity. These extensions were completed in 1891, and were designed and carried out by Mr. J. Kimber, M. Inst. C.E., Engineer to the Corporation. Sub-

sequent additional alterations include a new Worthington pumping-engine at Tallah, capable of raising 900,000 gallons per hour, and two triple-expansion Worthington engines, of greater power than the beam-engines. The system of supply remained unchanged.

The cost of the whole of the filtered-water works, up to March, 1899, amounted to 4,37,43,711 rupees, or about £3,000,000.

Settling-Tanks.—The six original settling-tanks are each 500 feet in length, 250 feet in width, and 7 feet to 9 feet in depth. They are constructed entirely of masonry, four of them being provided with a series of silt-catching pits, whilst the remaining two are plain. In practice no particular advantage is found to be gained by the use of the silt pits.

The new settling-tanks present more novel features; they are merely excavated in the soil, a poor sandy clay, and the banks are formed from the soil, puddling being dispensed with except upon the side of the tank next to the filter-beds (tank No. 1), Fig. 2, Plate 10. The other banks were formed by depositing the excavated material in layers of 1 foot in thickness, and consolidating them with water. In September, 1888, *i.e.*, towards the end of the rainy season, a breach occurred in the outer bank of tank No. 4, and with the outrush of water some 50 feet of the bank was carried away. Two days later the bank between tanks Nos. 3 and 4 gave way, making a breach about 30 feet in length. After repairing these breaches steps were taken to prevent the erosion of the repaired banks by the action of the waves; strong bamboo piles were driven at the toe of the slope, and the bank was pitched with rough-dressed stone. Other portions of the banks are pitched at the water-level with bricks set on edge. The percolation from the tanks is remarkably small considering the nature of the soil, the ascertained loss in depth being only $\frac{3}{4}$ inch in 24 hours and of this $\frac{5}{16}$ inch is accounted for by evaporation.

Filter-Beds.—The original filter-beds consist of 1 foot thickness of pebbles, ranging in size between that of a goose-egg and that of a pea, overlaid with 4 inches thickness of Mugra or coarse sand, and topped with 2 feet 6 inches thickness of fine river-sand. On passing through the filtering media the water is collected in small cross-drains 4 inches square in cross-section, covered with tiles spaced to permit the water to enter the drain. The cross-drains in each filter deliver the water into a collecting-drain laid along the middle of the filter, and these drains in turn deliver into a collecting-well from which the water flows directly into the conduit-pipes, Figs. 3, Plate 10. The new filter-beds consist of

two courses of dry bricks properly spaced to permit the passage of the water, overlaid with 4 inches thickness of Mugra or coarse sand, and topped with 2 feet 6 inches thickness of fine river-sand, Figs. 3, Plate 10. The two systems of filters appear to work equally well so far as the filtration is concerned, but the new filters are to be preferred as being more simple and more cheaply constructed, and are more easily cleaned than the original filters. The minimum thickness of sand permitted, before replenishing, is 1 foot. The average rate of filtration which has been found to yield the most satisfactory results is 40 gallons per square foot per day of 24 hours, the head of water varying between 3 inches and 20 inches. The filtrate is clear and bright excepting at the commencement of the rains, when an opalescent tinge is noticeable, which is probably due to iron and other compounds washed from the upper watershed by the first heavy rains. Analyses of the water after filtration are given in Appendix I. The number of bacteria in the filtered water now seldom exceeds 50 per cubic centimetre. The only suspicious feature in the bacteriological test is the continued presence of the bacillus *coli communis*, but this bacillus is common to most Indian surface-waters. The water compares very favourably with that supplied to other large towns, as shown in Appendix II. Fine sand in abundance is obtained from *churs* or sandbanks in the river, near the works. Mugra or coarse sand is obtained from the Mugra district, and pebbles are collected from the surface of the ground in the Raneegunge district. In washing the dirty sand no mechanical washers are employed. The dirty sand is placed in masonry tanks measuring about 12 feet by 12 feet by 3 feet, and having false bottoms, under which water from the settling-tanks is introduced. An objectionable feature of this method of washing is that it necessitates men standing in the tanks to agitate the sand.

Conduits.—The two conduits between Palta and Calcutta (Tallah Station) are 4 feet and 3 feet 6 inches in diameter and 66,000 feet in length, and work under heads of 12·2 feet and 9·5 feet respectively. They consist of cast-iron pipes with turned and bored joints. The calculated discharge of these pipes running full (by the Kutter formula, taking the value of n as 0·011), is :—

	Gallons per 24 Hours.
3-foot 6-inch pipe	7,640,000
4-foot pipe	12,616,000
Total	20,256,000

which approximates closely to the actual discharge.

Distribution.—The underground reservoirs at the distributing stations are filled during the night from Tallah pumping-station, the water being pumped through what is known as the independent pumping-main, a pipe 2 feet 6 inches in diameter reserved for this purpose only. The engines at the distributing stations complete the distribution into the service-mains. The distributing mains vary between 2 feet 6 inches and 9 inches in diameter, and parallel services between 6 inches and 3 inches diameter are provided for mains exceeding 1 foot in diameter. The total length of mains and services now in use in connection with the filtered supply is 315 miles.

Ferrule connections with the main are allowed to all pucca or masonry houses, the size of the ferrule varying according to the assessed annual valuation of the premises, or the gross annual rent less 10 per cent. in the case of rented premises. In the case of "bustees," or groups of native huts under one ownership, one or more connections were formerly allowed, according to the rateable value of the property, the taps being fixed in an open space accessible to all, but, under the new Municipal Act of 1899, connections are only allowed with pucca or masonry houses. In other cases water is drawn from standposts fixed at frequent intervals in the public streets.

The present practice in Calcutta is to maintain a pressure equal to a head of about 60 feet at the distributing stations between 6 A.M. and 10 A.M. and between 3 P.M. and 6 P.M. In addition a low pressure, sufficient to serve the standposts, is maintained during the remaining day hours in the more thickly-populated portions of the town.

The average daily consumption of filtered water in the town and suburbs now amounts to 20,356,873 gallons, which, for a population estimated at 843,487 (including floating population in port and canals), gives an average of 24·1 gallons per head of population per day. Filtered water is not used for road-watering or sewer-flushing.

In addition to the supply to the town and suburbs, water is also supplied to the cantonment at Barrackpur and to the municipalities of Dum Dum, Cossipur, Chitpur, and Manicktolla. The quantity of water so supplied is on an average about 300,000 gallons per day. Connections are not generally permitted, and the supply is drawn principally from standposts. The filtered supply to the town and the added area is distributed to 28,343 premises connected with the mains, 1,997 standposts, eight drinking-fountains, 224 hydrants for fire purposes, ninety-five cattle-troughs, and eighty-four public bathing-platforms.

The nature and habits of the population, and the tropical climate, in Calcutta, together with the dense population in portions of the town, render an ample supply of pure water a necessity, if the ravages of disease common under such conditions are to be successfully combated. A supply of 24·1 gallons of filtered water per head per day must, however, be considered an ample allowance for domestic purposes, as in addition to the filtered supply there is a copious supply of unfiltered water for use in road-watering and sewer- and privy-flushing. The existing intermittent supply of filtered water is unsatisfactory and its distribution is defective. The lavish use of the water, and the careless habits of the population, taps being constantly left open in all parts of the town, lead to considerable waste. Much of this waste is doubtless due to the fact that the supply is an intermittent one; the pressure being maintained for a few hours only during the day, the consumers leave the taps open to fill various receptacles. Another cause of waste is the state of some of the older mains and services laid in the town, which are believed to be unsound, but as an easy escape is provided by old sewers and drains, it it difficult to localize the leaks. As a remedy the Author has proposed to erect raised tanks in the town, through which the distribution would be effected, and which would act as reservoirs during the hours in which the engines were not at work. The Tallah pumping-station only would be retained to pump the water into the raised tanks, the remaining pumping-stations being closed. By the introduction of the Deacon waste-water meter system it is hoped that the waste of water caused by defective mains and services will be greatly reduced, and that it will then be possible to provide a constant or practically constant supply of water without increasing the supply.

Cost of Water.—The average cost of the filtered water, including all charges, repayment of loans and interest, amounts to about 2½ annas (which at the present rate of exchange represents 2½*d.*) per 1,000 gallons, the gross annual charges amounting to 12½ lakhs of rupees (£83,000). The following are the annual gross charges under different heads per million gallons of water pumped:—

	Rupees.	Annas.	Pies.		£	s.	d.
Annual gross charges, including interest and sinking fund . .	160	0	0	or	10	13	4
Annual gross charges, exclusive of interest and sinking fund .	50	0	0	„	3	6	8
Cost of coal	13	6	10	„	0	17	11
Cost of oil and engine-room stores	0	13	0	„	0	1	1
Cost of repairs to machinery .	1	0	0	„	0	1	4
„ filtering water . . .	6	0	0	„	0	8	0

The charges are met by levying a rate of 6 per cent. upon the assessed annual rateable value of properties assessed. The annual valuation of the property in the town is about 200 lakhs of rupees, or about £1,300,000.

Pumping Machinery.—Particulars of the pumping engines in use at the various stations and of their thermal efficiencies are given in Appendix III. The Worthington engines were all built by Messrs. James Simpson and Company, London; the beam-engines by Messrs. James Watt and Company, Birmingham; the inverted engines at Palta by Messrs. Fawcett, Preston and Company, Liverpool; and the direct-acting engines at Barrackpur by Messrs. Tangyes, Limited, Birmingham. The results afford a comparison between old and modern plants working under similar conditions. In the real test of efficiency—the British thermal units per pump-HP. per minute—it will be seen that the modern plants have a distinct advantage over the older, and the loss on working the heavy beam-engines against a comparatively low head of water is clearly shown, more especially in the case of the engines erected at Palta in 1888. These engines are of massive proportions, with heavy valves, and although the steam-consumption per indicator-HP. is normal, the consumption per pump-HP. on a lift of 20 feet to 30 feet is extremely high. With the exception of the Palta machinery, the engines are pumping against a head of between 70 feet and 100 feet.

Unfiltered Water-Supply.

In addition to the filtered water-supply, the town proper is in possession of a practically complete system for the supply of unfiltered water, which is used for road-watering, sewer- and privy-flushing, watering gardens and fire-extinguishing. This supply, as in similar instances of dual supplies elsewhere, had a comparatively small beginning. It was proposed by the late Mr. W. Clark, M. Inst. C.E., in 1871, when the filtered water-supply was fast becoming insufficient for the needs of the population. The quantity of water it was proposed to supply was 1,600,000 gallons a day, and the outlay was estimated at 1,81,112 rupees (£18,111), with working expenses at 12,853 rupees (£1,285) per annum. The scheme was eventually carried out, the old machinery and buildings used for the supply of the town prior to the introduction of the filtered supply being utilized for the purpose. Although the filtered supply was subsequently greatly increased, the idea of abandoning the unfiltered supply does not appear to have been considered; on the contrary, the old pumping-

machinery was replaced by two horizontal compound condensing engines, each of 180 HP., and each capable of raising 211,000 gallons per hour. These engines have, in their turn, been replaced by four three-stage expansion Worthington engines, each of 300 HP., and capable of raising 380,000 gallons per hour against a head of 140 feet. The system of pipes in connection with this supply is being extended into every sewered street, and already there are 116 miles of pipes laid, varying in diameter between 4 feet and 3 inches. The water is pumped direct from the river at the Mullick Ghat pumping-station, adjoining the floating bridge across the Húgli, and is delivered without any attempt at settlement or filtration. The average daily supply now amounts to 12,000,000 gallons, and is ample and practically constant, extending to 20 hours per day.

The machinery consists of four three-stage expansion, duplex, vertical, direct-acting engines of the Worthington type, built by Messrs. James Simpson and Company, London. The pumps are of the outside-packed plunger-type. Steam is supplied from four Babcock and Wilcox boilers fitted with mechanical stokers, and superheaters of the Babcock type. The amount of superheat obtained in ordinary working amounts to 137° F. Some difficulty was experienced in making the joints tight against the superheated steam, and cylinder-joints are now made with thin asbestos with brass wire-gauze insertion, steam-pipe flange-joints being made with corrugated brass rings. In the smaller steam-pipes flange-joints appear to be a necessity. The difficulty of lubrication was easily overcome by the use of a high-grade cylinder-oil. The water is pumped directly into the mains, without the intervention of stand-pipes or raised reservoirs. There are 3,898 hydrants fixed in the town, for purposes of road-watering, etc. The watering of roads is effected by means of a hose, the hydrants being spaced about 100 feet apart. Sewer-flushing is effected partly by automatic flushing-cisterns and partly by hose. Privies are flushed by means of waste-preventing cisterns.

Added Area.—The unfiltered water-supply has lately been extended to the added area, old machinery from the town station being utilized for the purpose. A new pumping-station has been erected on the river-bank at Watgunge and about 30 miles of pipe, varying between 2 feet 6 inches and 3 inches in diameter, have been laid in the streets which have been, or are to be, sewered. Two thousand hydrants are to be fixed upon these pipes for use in road-watering, sewer-flushing, fire-extinguishing, etc. The supply at present amounts, on an average, to about 350,000 gallons per

day, which will be greatly increased when the drainage-works now in hand are completed. These works were carried out under the Chief Engineership of Mr. A. J. Hughes, C.I.E., M. Inst. C.E.

Cost of the Unfiltered System.—The capital sunk in the unfiltered water system amounted at the end of March, 1899, to 26,07,370 rupees (£162,960). The cost of pumping the water for the year amounted to 51,903 rupees, and the quantity of water pumped to 3,465,384,165 gallons, an average cost of 3·03 pies or about $\frac{1}{4}$*d.* per 1,000 gallons.

In an inland town where ample water is available for filtering, the adoption of a dual supply must always be open to question, but once it is adopted, even upon a small scale, it is difficult to dispense with it. In Calcutta, owing to the exceedingly level nature of the land, the levels of the streets vary only to the extent of 3 feet or 4 feet, the sewers have but little fall, and a large quantity of water is required to flush them efficiently. The filtered water has to be brought from a distance, filtered and pumped several times before use, and were it used for flushing-purposes the supply would, for economic reasons, have to be curtailed. A large quantity of water is also required for road-watering, as little or no rain falls between the months of October and June. River-water is easily obtained all the year round, is drawn from a central point, and costs 0·84*d.* per 1,000 gallons, as compared with 2·6*d.* per 1,000 gallons for filtered water. The principal objections to the system lie in the cost of providing and maintaining separate systems of mains and pumping-stations, and the distribution, in a tropical climate, of water that is unfit for drinking-purposes and is at times charged with cholera and other dangerous water-borne bacilli. The latter objection is a most serious one when it is considered that the bulk of the native population are too simple and uneducated to realise the danger likely to arise from the use of such water.

The Author is indebted to The Honourable R. T. Greer, I.C.S., Chairman of the Corporation, and to Mr. T. C. Deverell, M. Inst. C.E., Chief Engineer to the Corporation, for permission to publish the information contained in the Paper.

The Paper is accompanied by three drawings, from which Plate 10 has been prepared, and by the following Appendixes. The drawings were made by Mr. J. Kimber, M. Inst. C.E., who was for many years Engineer to the Corporation.

[APPENDIXES.

APPENDIXES.

APPENDIX I.

Analysis[1] of Filtered Water.

(Parts per 100,000.)

Date and Place of Collection of Sample.	Total Solids.	Chlorine.	Saline Ammonia.	Albuminoid Ammonia.	Total Hardness.	Permanent Hardness.	Nitrogen as Nitrates and Nitrites.	Oxygen absorbed in 15 Minutes.	Sulphates.	Nitrites.
Laboratory tap, 15 April, 1901 . . .	27·0	1·3	Nil	0·004	12·75	3·75	0·023	0·008	Trace	Nil.

Bacteriological Examination.

(*a*) Number of microbes per cubic centimetre, as shown by Agar-plates kept at 37° C. for 3 days	89
(*b*) Microbes which are evidence of pollution—	
1. Comma bacillus	Not present.
2. Bacillus Typhi-Abdominalis	„ „
3. Bacillus Coli-communis	Present.
4. Bacillus Enteritidis Sporogenes	Not present.

Before filtration the analyses gave the following results during 12 months:—

	Parts per 100,000.
Total solids	29 to 104
Chlorine	0·04 „ 1·6
Saline ammonia	Nil
Albuminoid ammonia	0·008 to 0·0304
Total Hardness	8·5 „ 17·25
Permanent hardness.	2·5 „ 5·25
Nitrogen as nitrates	0·026 „ 0·049

The average total solids during the four quarters of the year, after settlement during 54 hours to 61 hours, amounted to 28·3, 27·0, 27·2 and 21·8 parts per 100,000 respectively.

[1] Made by Mr. J. N. Dutt, B.A., M.B., Assistant Analyst, 19 April, 1901.

APPENDIX II.

Comparison of Analysis of Water-Supplies in large Indian Towns.

Report by Mr. J. Nield Cook, D.P.H., Health Officer, 26 February, 1901.

"With reference to the analysis of water received from Bombay, Madras, Benares, Agra, and Jabalpur, as they were given in different systems of numeration and related to different months, I have reduced them all to parts per 100,000 and compared them with the Calcutta water for the corresponding month in the Table given below.

(1) "Comparing Bombay, Madras, and Calcutta, Calcutta shows the best results throughout. As regards bacteria, the Bombay water contained 1,060, the Calcutta 164 per cubic centimetre. Bacillus Coli-communis was not present in the Bombay water, though it was found in the Calcutta supply. I am informed that it has been present in the Bombay supply during a part of the year. The absence of even a trace of free ammonia and small quantity of albuminoid is a good feature of the Calcutta.

(2) "There is little to choose between the Agra and Calcutta water analysed in January.

"The Allahabad water on the ammonia may be pronounced decidedly inferior to both of them.

(3) "The analyses of Jabalpur and Calcutta water for July show the latter to be appreciably the better. The Secretary to the Karachi Municipality sends an analysis for July, 1894, since which no analysis has been made. I do not think it would serve any useful purpose to bring this into the comparison, but I may state generally that it is inferior to the Calcutta supply.

(4) "The analyses of Benares and Calcutta for October show the Calcutta water to be decidedly the better.

(5) "On the whole the Calcutta water compares favourably with that of other large towns in India."

Analyses of Water in Parts per 100,000.

——	Total Solids.	Chlorine.	Free Ammonia.	Albuminoid Ammonia.
November.				
Bombay	9·3	1·6	0·0014	0·009
Madras	29·0	4·97	0·001	0·033
Calcutta	15·7	0·52	..	0·0038
January.				
Agra	18·0	2·0	..	0·002
Calcutta	22·6	0·88	..	0·0047
Allahabad	16·0	1·8	0·003	0·002
July.				
Jabalpur	9·3	0·8	0·008	0·012
Calcutta	12·0	0·59	Trace.	0·003
October.				
Benares	10·0	1·0	0·0035	0·008
Calcutta	11·7	0·5	..	0·003

APPENDIX III.—Particulars and Thermal Efficiencies of Pumping-Engines.

Name of Station.	Description of Machinery. No. of Engines.	Type.	Size.	Date of Erection.	Thermal Efficiency. Steam-pressure by Gauge.	Temperature at Stop Valve, °F.	Temperature of Exhaust, °F.	Indicator-HP.	Pump-HP.	Weight of Steam used per Minute.	British Thermal Units per Minute.	B.T.U. per Minute per Indicator-HP.	B.T.U. per Minute per Pump-HP.	B.T.U. theoretically required.	Efficiency Ratio.	Thermal Efficiency.
Mullick Ghat	4	Three-stage expansion surface-condensing vertical Worthington[1]	Inches. 14, 21 & 35 × 42	1898	95	461	183	183	169	55·12	60,392	330	357	240	0·717	0·189
Tallah	2	Compound condensing beam	..	1869	..	..	..	..	..	..	..	..	..	..	..	..
"	2	Three-stage expansion surface-condensing horizontal Worthington	17½, 27 & 42 × 42	1898	..	..	..	..	..	..	..	..	..	..	..	..
"	1	Three-stage expansion jet-condensing horizontal Worthington	21, 30 & 51 × 60	1894	85	308	122	520·5	394	152·26	161,889	310	410	190	0·612	0·134
Palta	3	Inverted	27 & 45 × 48	1888	80	320	130	164	96	38·89	46,938	286	488	190	0·664	0·148
"	3	Compound jet-condensing beam	20¼ & 32⅝ × 44 & 60	1869	37	279	185	70	43·5	18·92	20,786	296	476	232	0·783	0·143
Bhowanipur	2	Three-stage expansion jet-condensing Worthington	11, 17½ & 28 × 30	1891	140	344	141	96	86·3	25·13	32,356	337	374	175	0·519	0·125
Halliday Street	4	Compound jet-condensing beam	20 & 32½ × 44¼ & 60	1889	66	306	144	82·1	62·2	24·08	29,064	321	424	218	0·678	0·182
Wellington Square	3	Compound jet-condensing beam	24¾ & 39½ × 52 & 72	1869	80	300	150	142·5	88·5	40·34	44,371	312	501	230	0·734	0·185
Barrackpur	2	Tangye direct-acting	7 & 12 × 18	1882	..	..	..	..	..	..	..	..	..	..	..	..
Watgunge	2	Compound horizontal jet-condensing	18¼ & 13¼ × 48	1899[2]	..	..	..	..	..	..	..	..	..	..	..	..

[1] Babcock superheater in use, giving about 140° superheat.

[2] First erected 1884.

(*Students' Paper No. 473.*)[1]

"The Newent Waterworks of the Gloucester Corporation."

By Harry Oscar Jones, Stud. Inst. C.E.

The population supplied from the Gloucester Corporation Waterworks at the present time is between 50,000 and 55,000 persons, and the supply is obtained from three sources, namely, Witcombe, Robinswood Hill, and Newent. Previous to the completion of the Newent Works, the water-supply was taken from three reservoirs, having a capacity of 120 million gallons, constructed in the Lower Lias clay, at the foot of the Inferior Oolite formation of the Cotswold Hills, at Witcombe, some 5 miles east of the City; and two small reservoirs of 10 million gallons capacity, in the Lias at Robinswood Hill, an outlier of the Cotswold Hills, within the present City boundary. The water from these sources is delivered by gravitation through a 12-inch main from Witcombe, and through one 6-inch and one 9-inch main from Robinswood Hill.

In 1879 the Council of Gloucester appointed a committee to consider the question of an additional water-supply, as it was foreseen that the requirements of the district would soon render this necessary. The late Mr. J. F. La Trobe Bateman (Past-President Inst. C.E.), recommended, in 1880, that a tunnel be driven into the hill at Birdlip, adjacent to the Witcombe reservoirs, but this scheme was vetoed by the Local Government Board in 1883, when application was made for their sanction. After this the Corporation, on the advice of Mr. R. Read, Assoc. M. Inst. C.E., the City Surveyor, adopted the Deacon system of waste-water detection, which was installed at a cost of some £2,000, and by means of which the daily consumption per head for all purposes was reduced from 32 gallons to between 15 and 18 gallons. This allowed a constant supply to be maintained, except in very dry summers, such as that of 1890, until the opening of the Newent Works removed the necessity for such strict economy; it may be mentioned, however, that the

[1] This Paper was read and discussed before a meeting of the Manchester Association of Students of the Institution on 10 April, 1901.

present rate of consumption seldom exceeds 20 gallons per head per day, owing to the use of the Deacon system. In 1890 it became evident that, even with the strictest economy of consumption, a new source of supply would have to be considered; and Mr. W. Fox, M. Inst. C.E., after investigating and reporting on ten proposed schemes, finally recommended the construction of the Newent Works. After conferring with Mr. Robert Etheridge and Professor Lapworth on the geological aspects of the scheme, it was submitted to Mr. James Mansergh (Past-President Inst. C.E.), who endorsed Mr. Fox's recommendations; the scheme was accordingly adopted and a Bill was promoted in Parliament for carrying out the work.

The site of the works is at Oxenhall, near the small market-town of Newent, and about 11 miles west of Gloucester. The trial boring was commenced on the 3rd January, 1893, with a 12-inch diamond-drill, and at a depth of 66 feet in the Keuper beds of the New Red Sandstone, after passing a 4-foot bed of conglomerate, water was reached, at a pressure which caused it to overflow on the surface. The boring was taken down to a depth of 290 feet, by the Corporation, at a cost of £600; the landowners continued the boring to a depth of 1,190 feet in the hope of finding coal, but as at that depth the bottom of the Bunter beds had not been reached they abandoned further boring. Geological maps show that the boring is between two parallel faults running almost north and south, with the Syenite of the Malvern range some 7 miles to the north, and the Silurian of May Hill 3 miles south. The western fault is of great extent, and has on the surface, on its east side, the Keuper beds of the New Red Sandstone, in which the boring was made, the Old Red Sandstone being on the surface on the west side. All along this western fault, from Retford Bridge on the River Leadon on the north, to Great Boulsden on the south, small outcrops of coal are found; and several years previously a colliery shaft sunk at Oxenhall, right on the fault, yielded an abundance of water but very little coal, and it was mainly this fact which in the first instance drew attention to Newent as a possible source of supply. As the boring showed that the bottom of the Bunter beds had not been reached at a depth of 1,190 feet, and as these beds crop out on the surface, with the brecchia or pebble beds of the Permian formation, at a distance of 6 miles north-east, it was fairly assumed that they were in a wedge-shaped trough of the New Red Sandstone at least 1,200 feet deep at the bore-hole, thinning out some 6 miles away at Bromsberrow, where the ground is about 200 feet higher than the

bore-hole, the top of which is 102·5 feet above Ordnance datum. In boring it was found that for the first 300 feet the strata consisted of beds of conglomerates, marls, and sandstones, but below this depth only sandstone, of varying hardness, was found.

The works, which were designed by, and constructed under the superintendence of, Mr. W. Fox and Mr. R. Read as joint engineers, consist of a well, 168 feet in depth, from which the water is pumped to a small service-reservoir, whence it gravitates to Gloucester; the total cost was about £45,000.

The Act authorising the work received Royal Assent on the 26th July, 1894, and on the 16th August the Council accepted the tender of Messrs. Timmins and Sons of Runcorn for the well-sinking. The first sod of the well was cut on the 8th October, 1894, and the work then proceeded. The well was sunk 15 feet in diameter for the first 60 feet, and was lined with brickwork, the finished internal diameter being 12 feet; between 60 feet and 150 feet in depth the well was reduced to 12 feet in diameter, and was lined with cast-iron cylinders, in 5-foot lengths, each length being in eight sections. From the last ring but one, at a depth of 145 feet, two headings, each 6 feet 6 inches by 4 feet 6 inches, were driven, for distances of 145 feet and 117 feet respectively. In driving the latter heading, what was apparently a large fissure acting as an underground reservoir was unexpectedly encountered, and water came into the heading in such quantities that the men had to beat a hasty retreat, and further driving was abandoned in that heading.

In sinking the well the New Red Sandstone was found at a depth of 11 feet, with beds of hard marls and conglomerates. At a depth of 19 feet, in a bed of conglomerate, part of an elk's horn was found, and at 52 feet in depth some petrified timber was discovered. The dip of the strata was found to be about 1 in 60 from west to east, to a depth of about 40 feet, where it began to increase until at 126 feet in depth it was 1 in 12. The water overflowing from the bore-hole, which was about 100 yards east of the well, was not affected until a depth of 26 feet was reached; and the water-level in the colliery shaft, 1 mile north-west of the well, which was 46 feet from the surface at the commencement of the well-sinking, was not altered until a bed of conglomerate, which extended from 58 feet to 88 feet in depth, was passed, on 26 May 1895. This bed was very hard, with traces of iron and large pebbles, some of them 4 inches in diameter. The next 11 feet in depth consisted of sandstone and a dark broken conglomerate, and from 99 feet to 110 feet in depth occurred conglomerate with 6-inch pebbles imbedded, followed by a very dark mottled conglomerate to a depth of 115 feet.

Then occurred in succession 7 feet in depth of grey rock and conglomerate, 6 feet in depth of hard red sandstone, and 17 feet in depth of mottled conglomerates, terminating at a depth of 145 feet, at which level the headings were driven. Between 145 feet and 168 feet in depth hard red sandstone only was found. The cost of the well and headings was £4,586, including the necessary pumping during the sinking of the well. As it was found that the well drained the water from the wells at Oxenhall Court and Whitehouse Farm, both being very deep and about a mile away, a 4-inch main was laid from the pumping-main, dividing into two 3-inch branches, to supply the places named.

The service reservoir is situated on an eminence at Madam's Wood, Upleadon, 3 miles from the well, and 8 miles from Gloucester; the top water-level is 150 feet above the sill of the well, and 200 feet above Gloucester Cross, the business centre of the city. The reservoir, like most service reservoirs, is constructed partly in excavation and partly in embanking, and is 100 feet in length and 60 feet in width, in internal bottom dimensions, and 18 feet in depth to top water-level, with a capacity of 650,000 gallons. The walls were built before the material in the centre was excavated, but the trench for them was made wide enough to allow of the concrete floor being put in for a width of about 2 feet from the inner toe of the wall at the same time that the wall-foundations were put in. The walls are composed of large rubble masonry in cement-mortar, the stones being flat-bedded; at least 20 per cent. of the stones weighed 3 cwts. each and upwards, 30 per cent. between 2 cwts. and 3 cwts., and 30 per cent. between 1 cwt. and 2 cwts. The stones were roughly squared, and the face-stones were roughly dressed to a batter of 2 inches to a foot. The larger stones were laid first in each course and were well beaten down on the bed of mortar, no two stones touching, the interspaces being filled in with smaller stone and the whole well grouted. The stones were laid to break joint horizontally as well as vertically as much as possible, and the face-joints were left open to form a key for the rendering. The walls are 7 feet in thickness at the bottom, diminishing to 2 feet 6 inches at the water-level, being stepped at the back. The embankments were formed from the material obtained from the excavation, with a slope of 2 to 1, and were brought up as the walls proceeded, in 2-foot layers, sloping slightly towards the walls; the driest or most stony material was placed nearest the face of the slope, and the most clayey material inside, all being well rammed for a distance of 2 feet from the back of the wall.

After settlement the slope was covered with 9 inches of soil, and was sown with grass. The floor is of concrete, 1 foot 3 inches in thickness, with extra thickness where the pipes pass through the walls; the concrete is composed of 1 of Portland cement to 5 of broken stone and sand, and was put on in two layers, breaking joint at least 2 feet horizontally, the top layer being smoothed over. All the stone used, both for walling and concrete, was red Forest of Dean sandstone, from the Wilderness quarries. The inside of the walls is rendered in one $\frac{3}{4}$-inch layer of cement and sand, gauged 1 to $1\frac{1}{2}$, floated over smooth. The roof rests on steel girders, 1 foot by 6 inches in cross-section, supported on piers, 2 feet 3 inches square, of brindled Staffordshire bricks, in cement-mortar, with three courses of footings resting on the concrete floor, and capped with ashlar bedstones 9 inches thick. Ashlar bedstones are also built into the wall to take the ends of the girders. The girders are bedded on these stones with a $\frac{1}{2}$-inch space between the ends of each length, and are kept in place at the ends by wrought-iron tie-rods. The roof is of concrete arches in spans of 12 feet 4 inches, with a rise of 2 feet 6 inches. The arches are 1 foot 6 inches in thickness at the crown, and at the springing the thickness varies between 3 feet at the centre of the reservoir and 2 feet 6 inches at the sides, to allow a fall of 6 inches for drainage of the valleys between the arches. Drain-tiles 3 inches in diameter are laid along the valleys, and the whole is covered with 1 foot 6 inches of soil, and sown like the slopes. A manhole with a cover is fitted at one end of the reservoir, over the 14-inch outlet, with a wrought-iron ladder for access, and a valve-chamber is placed at the foot of the embankment. Water is admitted either by a bell-mouthed stand-pipe or through a valve at its foot, both being 1 foot 2 inches in diameter, and the reservoir is ventilated by cast-iron cowls placed along the crowns of the arches. The reservoir was constructed by Messrs. Cruwys and Hoborough, of Gloucester and Birmingham, at a cost of £2,181.

The pumping-station is built of brick, with facings of Wilderness stone, and was erected at a cost of £3,766; the contractor for this part of the work became involved in financial difficulties soon after starting, and the Corporation took possession of the plant and materials on the site, and completed it by day-work, the Clerk of Works taking charge of the building-work, and at the same time superintending the erection of the engines. When pumping was stopped, the level of the water in the well was higher than that of the bottom of the foundations, and in order to free them as much as possible a line of 12-inch stoneware pipes

was laid to the adjacent Ell Brook, at a level of 9 feet below that of the basement floor. A brick catch-pit, built on the line of this drain, received the drains from the boiler and rain-water pipes, watertight back-flap valves being placed on the mouths of all drains entering the catch-pit, to prevent water from the brook entering the well when the brook is in flood. The foundation for the engine-beds and main air-vessel is of concrete to the basement level, above which it is of Staffordshire bricks in cement; the bedstones themselves are 1 foot 6 inches thick. The chimney shaft is 10 feet square in outside dimensions at the base, tapering to 5 feet 9 inches square at the top, with a moulded stone cap. The stack is 86 feet in height from the invert of the flue to the top of the cap, and 3 feet 6 inches square in internal dimensions, the bottom 26 feet being lined with 4½ inches of firebrick set in fireclay. A lean-to glass roof with Helliwell glazing is constructed over the economiser. Brick pilasters with ashlar caps are built on the inside of the engine-house wall to carry the girders on which the crane travels. The erection of a house for the chief engineer at the pumping-station cost £703; and the cost of approaches, fences, etc., including the embankment for the roads, amounted to £760; the contractor for the engineer's house was Mr. Bidmead, of Newent, and the approaches were constructed by day-work.

The engines, pumps and boilers were constructed and erected by Messrs. Summers and Scott, of Gloucester, at a cost of £5,415. The engines and pumps are in duplicate, and are of the inverted-cylinder vertical type. Each engine drives two pumps, one a lift-pump in the well, and the other a force-pump which forces the water up to the reservoir.

The lift-pump is driven from the high-pressure cylinder by means of a bell-crank lever worked from the crank-pin by a connecting-rod; the horizontal force-pump is driven from the crank-pin of the low-pressure cylinder by means of a similar connecting-rod and slide-blocks. The engines are arranged back to back, one lift-pump being down each side of the well, and the two force-pumps close together. The lift-pumps are bolted to girders placed across the top of the well, their top portions consisting of castings with flanges, for securing them to the girders, and a gland in which the plunger on the top of the pump-rod works. The pump-rods are of steel, 2¼ inches in diameter, jointed with treble scarfs, with cast-steel boxes outside and wedges driven in. The pump itself is lined with gun-metal and fitted with an ordinary four-faced valve, the foot-valve and all the

pump-valves being also of this type. The lift-pump was originally fitted with phosphor-bronze packing-rings, but in consequence of sand, etc., rising with the water these rings were found to give a good deal of trouble, and after some experimenting the buckets were filled with white metal; this has proved very satisfactory, as it yields to any particularly hard substance that may get in, and prevents the pump becoming jammed. The rising-main in the well consists of steel tubes, 1 foot 4 inches in diameter, to the bottom end of which the pump is secured, the whole being suspended in the well so that it can be lifted out without difficulty. One of these pumps has been lifted out and replaced in 4 days, as all that is necessary is to remove the bell-crank and the slide-bars guiding the plunger. The diameter of the lift-pumps is 1 foot 2¾ inches, and the stroke 4 feet 3 inches. The plunger is driven from the bell-crank lever by means of links, the inner end of the lever being fitted with a cast-iron balance-weight which balances the plunger-rods and bucket with half the load, so that the work, instead of being done in the one stroke, is divided between the two strokes of the engine. The water is delivered into a tank, passing through a number of 1½-inch brass tubes in the surface-condenser, the whole body of which is below the level of the tank. The lift-pump being rather larger than the force-pump, the quantity lost is not so much as the difference between the capacities of the two pumps, so that there is no difficulty in maintaining an ample supply to the force-pump. This is of the horizontal double-acting type, bolted down to the main engine-bed, and is 10½ inches in diameter, and 4 feet 6 inches stroke; it is lined with gun-metal, and fitted with a gun-metal piston packed with phosphor-bronze rings, and is connected to the bottom of the air-vessel. Both engines pump into a common air-vessel 13 feet in height and 4 feet in diameter, having a steel body and cast-iron ends, the main to the reservoir passing from the bottom.

The cylinders are supported on A-shaped frames, which also carry the platform round them; the high-pressure cylinder is 16 inches in diameter, and the low-pressure cylinder 28 inches in diameter, both having a stroke of 4 feet 6 inches. They are steam-jacketed round the sides and bottom, as is also the intermediate receiver between them; the jackets are arranged so as to drain themselves automatically back to whichever boiler is at work, without the intervention of any steam-traps or valves. The crank-shafts are of steel, the cranks being shrunk on while hot, and are 8 inches in diameter at the bearings, and 11 inches at the centre. The fly-wheels are 16 feet in diameter, and weigh

about 12 tons each; each is fitted with a toothed ring in which works an automatic barring-gear which throws itself out when the engine starts. A travelling crane runs the whole length of the engine-room, and is capable of lifting 10 tons. The well is fitted with a level-indicator, worked by an endless chain fitted with a hollow float on one side and a weight on the other, the water-level being shown on a dial-plate.

The boilers are three in number, and are of the Lancashire type, 6 feet in diameter by 22 feet in length, the flues being 2 feet 6 inches in diameter; they work at a pressure of 100 lbs. per square inch, but are designed to work at 120 lbs. per square inch; a Green economiser is placed in the flue between them and the chimney.

The average consumption (Welsh coal being used) is about 1·68 lb. per indicator-HP. per hour; the amount of water pumped by each engine at 18 strokes per minute is about 30,000 gallons per hour, the average amount of coal consumed being about 1 lb. per minute during pumping. The staff at the pumping-station consists usually of an engineer, an assistant, a fireman and a labourer, the weekly wage-bill amounting to about £6 10s. Pumping is usually continued for 12 hours per day, except when for some reason the Witcombe supply is turned off. In such cases both engines are used, and pumping has to be carried on both day and night, the staff being increased by another fireman and driver being sent out from Gloucester. This is necessary, on account of the small capacity of the service-reservoir, to remedy which another reservoir of practically double the capacity and of similar construction, excepting that the walls will be of concrete instead of stone, is in course of construction alongside the existing one. The yield of the well was estimated, before the construction of the works, at 650,000 gallons per day, and for this assumed quantity the present reservoir was constructed, but it was found that the yield was much greater than was anticipated; in fact, in the winter of 1899–1900 the water pumped amounted to 1,500,000 gallons per day.

The main was laid by Messrs. Cruwys and Hoborough, the contractors for the reservoir, and consists of 3 miles of pumping-main between the well and the reservoir, and 8 miles of gravitation-main from the reservoir to Gloucester, both mains being 1 foot 2 inches in diameter, and, in general, laid along the road-side. The pipes were supplied by Messrs. Cochrane and Comp[any] of Woodside, and the valves by the Glenfield Company, of Kil[mar]nock; the pipes were laid at an average depth of 2 feet 9 in[ches] to the top. Several brick-arched bridges over streams, belong[ing] to the County Council, were crossed, and in these cases the bri[dge]

work was cut away sufficiently to allow of the insertion of a cast-iron trough-girder, with its ends bedded on an ashlar template, the space round the girder being afterwards made good with brickwork. The pipes were laid in this trough, the sockets being bedded on asbestos mats, the space under and round the pipe was filled in with earth, and the footway above was made good. At Barber's Bridge, where the main crosses a bridge over the Great Western Railway, one of the brick arches of the bridge between the girders was removed, to allow of sufficient depth for the pipe, and was replaced by a bent iron plate ½ inch thick, covered with 9 inches of concrete. At Over Junction, near Gloucester, the pipes were carried under the Great Western Railway lines in culverts 5 feet 6 inches square in cross-section, the sides and roof being of 14-inch brickwork, and the floor of 12 inches of concrete; the pipes were supported on concrete blocks on the floor, put in after the pipes were laid. A 6-inch drain is carried from the lower end of each culvert to the River Severn; these are fitted with flap-valves at their discharge-ends, as the culvert-floors are below high-water level; access to the culverts is obtained by means of man-holes in the railway embankment. The 14-inch main from Newent is connected to the 12-inch main from Witcombe, so that a large part of the city is supplied with "mixed" water. Stop-valves, sluices and air-valves were fixed where required on the main, and the cost was £10,373 for pipes, £318 for valves, etc., and £4,025 for laying and fixing, being an average of 14*s*. 6*d*. per yard run. The main was carried over the western branch of the Severn by a steel lattice-girder bridge of 212 feet span. Each end of the bridge is carried on a group of four cast-iron screw-piles connected by box-girders of channel section, to which the main-girder bearings are bolted. The piles are each 15 inches in diameter, and 1¼ inch thick, the flush spigot-and-socket joints being strengthened by steel collars shrunk on, and the whole filled with concrete after the piles had been screwed to a firm foundation (the Lower Lias clay), which was reached at a depth of about 43 feet; the test for settlement was a weight of 30 tons placed on the top for 7 days. The main girders are of steel, 222 feet in length over all, with a 6-inch camber in the centre; one end of each girder is fitted with turned steel roller-bearings, and the other is bolted to cast-iron chairs. The bottom booms of the girders are connected by rolled joists resting on the angles, and riveted to the inner side-plates by angle-pieces. The vertical bracing is stiffened in the centre by H pieces, and the wind-ties are of T section, placed transversely and diagonally to the main girders, the ends being bent to bear properly on the curve of the

top boom. The bridge was erected on the bank of the river, and was floated across on barges. The pipes are laid on the rolled joists between the bottom booms, and are covered with Toupe woollen sheathing, tarred and covered with thin sheet lead, which however soon showed signs of peeling off, and wooden boxing filled with slag-wool was therefore fixed in addition. The contractors for the bridge were Messrs. Lysaght and Company, of Bristol, and the contract price was £1,766, which did not include the pipes, expansion-joints, and valves.

The water was turned on to the city on the 1st July, 1896, but the work was at that time by no means completed. The water was then very low in the Witcombe reservoirs, and arrangements were made with Messrs. Timmins and Son, the contractors for the well, for their pumps to remain and pump water to the reservoir until the permanent pumps were fixed. The works were finally completed in 1897.

The following is the result of the analysis of the water from the well:—

	Parts per 100,000.
Total solid matters	34·60
Organic carbon	0·008
Organic nitrogen	0·002
Ammonia	0
Nitrogen as nitrates and nitrites	0·297
Chlorine	1·8
Hardness, Temporary	17·2
" Permanent	7·9
Total	25·1

The hardness of the water is its only slight drawback; Dr. E. Frankland reported in 1893 that it was one of the most organically pure he had ever examined. The question of softening the water has been before the Gloucester Council more than once, but so far nothing has been done in that direction; naturally the chief objectors to the use of the water in its unsoftened state are the manufacturers, on account of the scale which it produces in boilers, but for all dietetic purposes it is of excellent quality.

In conclusion, the Author desires to express his indebtedness to Mr. R. Read, Assoc. M. Inst. C.E., the City Surveyor of Gloucester, for much of his information regarding the works, and also to Mr. C. H. Scott, of Messrs. Summers and Scott, Gloucester, for a great part of the description of the engines and pumps.

(*Students' Paper No. 474.*)

"The Testing of Combined Steam-Engine and Dynamo Sets." [1]

By Edwin Hartree Rayner, B.A., Stud. Inst. C.E.

The exacting requirements of engineers and others, in specifications relating to the economy of generating-plant, have caused makers of engines used for the generation of electricity to install apparatus for the rapid testing of steam-dynamo sets. This comprises special steam-raising plant, arrangements for controlling and dissipating the electrical output, and instruments for its measurement and for the measurement of the steam used by the engine. In the following Paper the Author proposes to outline the tests usually applied to such sets, and the methods used in the testing-shops of engine makers.

In England, where the manufacture of engines and dynamos is largely carried out by separate firms, the dynamo is usually sent to the engine maker with a coupling on the armature-shaft, by which it is fixed to the crank-shaft of the engine. The engine maker fits the two together and steams them according to the tests required. By this means, in a few hours, an insight is obtained into the economy of the set, such as it is almost impossible to acquire in a central station or private installation. The engine builders obtain, at the same time, data for future orders, and are able to effect improvements which would hardly be possible except by having most of their engines steamed under the eyes of men whose work it is to get engines to run satisfactorily, and who have had much experience of former engines. Satisfaction is given to customers by the fact that when finally erected the engines usually run satisfactorily at once. The performance of these tests is an important item in the cost of the engine to the builder. The methods now employed in all tests where reliable results are required in a reasonable time were instituted by the late

[1] This Paper was read and discussed before a meeting of the Manchester Association of Students of the Institution on 20 February, 1901.

Mr. Willans[1] at Thames Ditton. High-speed-engine builders have now erected special buildings and laid down plant at considerable expense for the purpose; and engines up to about 1,200 HP. are now usually tested before leaving the works. Engines of over 1,500 HP. are more conveniently tested on site after erection, on account of the large boiler-power required and the cost of such a trial.

In the following Paper the Author proposes to deal chiefly with the work done in the testing department of Messrs. Willans and Robinson's works at Rugby. This department has been built entirely separate from the rest of the works. The engines (small sizes complete, ready for the steam- and exhaust-piping; larger ones in parts) are brought on trolleys running on rails from the erecting-shop, the men from which erect the engine on the steaming-beds. The boiler-power required is considerable, as several engines are often running at once, if not on official trial, yet on preliminary runs to see that all is satisfactory. The rapid fluctuation in the demand for steam, due to the engines being continually started and stopped, necessitates the employment of a boiler readily controllable as to rate of steam-production; and, as it is usual to run all engines off a common steam-pipe, the boilers must easily maintain the highest pressure required by modern triple-expansion engines, viz., about 200 lbs. per square inch. These requirements are best fulfilled by water-tube boilers, and at Rugby there are installed four Niclausse water-tube boilers rated at 250 HP. each, but which easily produce 400 HP. They are also used to supply steam, day and night, to two engines driving the dynamos which supply power for the travelling cranes, forty in number, the pattern-shop machinery, circulating pumps for the condensers, and for lighting the whole of the works. These engines are three-throw engines of standard pattern with two-pole dynamos, rated 900 amperes at 120 volts. A power-house is now in course of construction, in which electricity will be generated for works' use; electrical power-transmission will soon be completely installed for all purposes, and larger generators will be used. The steam arrangements include three duplicate feed-pumps, a Green economiser of 192 tubes, with motor-driven scrapers, and two motor-driven circulating-pumps for the surface-condensers. The water is purified in two settling-tanks, in which it is softened by the Archbutt-Deeley process. A railway siding passes the boiler-house door, and the covered bunkers are capable of storing large quantities of coal.

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[1] Minutes of Proceedings Inst. C.E., vol. xciii. p. 128, and vol. cxiv. p. 2.

The testing-shop consists of four bays, in which the dynamos and condensers are placed. Each is served by two electrically-driven travelling cranes. In the front, away from the boiler wall, there is a pit, 3 feet in depth and 6 feet in width, in which the field-magnets of large machines are fixed, and over which large fly-wheels are hung, as by this means the engine itself is kept down and is therefore more easily steadied. There is also in one bay a shorter parallel pit. The engine bed-plate is usually planed underneath and supported on girders about 1 foot high, which are bolted to cast-iron slots grouted into the cement floor. In small sets the magnets are fixed on the same bed-plate as the engine, and in larger sets they have to be packed up to the required height either from the floor-level or from the pit-bottom. The floor furthest away from the boilers is raised, and on it the engines are placed after the trial, and are taken down, examined, oiled, and, in the case of the smaller ones, re-erected.

All electrical readings are made in the weigh-bridge room, where the steam used by the engine is weighed after it comes out of the condenser, and where practically the whole trial is made. There is also an underground system of pipes by which the exhaust of an engine may be taken to the atmosphere. One person sitting before the weigh-bridge beam has before him a clock, on the one side a bell to signal to the driver or persons indicating the engine, on the other the shunt-resistance controlling the output of the machine, and in full view the scales reading by reflected light the output of the machine. By this means the consumption of steam by the engine is obtained in a few minutes with greater accuracy and satisfaction than if it were done by the older method of measuring the feed-water supplied to the boiler, which, with all its losses and inaccuracies, would require as many hours. It would be the work of several days to obtain satisfactory results by the latter method from an engine tested at full, three-quarter, half and quarter load, both condensing and non-condensing, such as can be done by the former method between breakfast- and dinner-hour.

Numerous pipes supply live steam to the engines by means of temporary copper and wrought-iron piping, and there is usually a separator for removing the water in the steam on the engine bed-plate, as well as separators permanently fixed to the steam mains. Loose flanges enable the connection of the temporary steam-piping to be easily made. The condensing water is taken from a main supply-pipe by means of flexible pipes, and is discharged through a special drain into one of the condensing ponds. The steam used

by the engines is condensed in a surface-condenser, and gravitates into one of two tanks on weigh-bridges. In the case of condensing trials, it is pumped out of the condenser by the air-pump. The layer of oil on the top of the water prevents any undue evaporation from the surface of the warm water in the weigh-tank. The main current from the dynamo is carried by temporary cables to terminals on wooden boards fixed on the pillars supporting the roof. The mains run to the screw-plug testing switch-board, from which some twenty circuits lead to resistances in the resistance-room, where the energy is dissipated by passing the current through iron-wire netting or through water-tanks. To smaller terminals are connected two wires from the main terminals of the machine, by which the effective voltage is measured, and two others are similarly provided for the exciting circuit, whether the machine be self- or separately-excited.

The field-coil circuit is taken to the instrument room, where temporary connections are made to shunt-resistances and switches, and an ammeter is placed in the circuit. By means of the shunt-resistance the load on the machine is adjusted. In ordinary working the field-coils of a shunt-wound machine gradually increase in resistance after running for some time, as they become heated by the current. The extra resistance in the circuit has therefore to be reduced as the machine becomes warm, if the voltage is to be kept constant. The testing switchboard on the gallery is divided into an upper and a lower panel, one for each pole of the machine. It consists of a number of horizontal bars to which the machine terminals are connected; and at the back of the switchboard are a number of vertical bars, connected to resistances in the resistance-room through a switch, by the making or breaking of which the load, or part of it, is put on or taken off the machine being tested. By screwing plugs into holes in the back bars, any machine may be put on to any of the resistances in the resistance-room. In the latter the frames are arranged, chiefly by means of copper connections in mercury cups, to suit the voltage of the machine. The current, per switch, is usually about 100 amperes with 500-volt machines, and 200 amperes or more at lower voltages. By means of copper bars from the adjacent lighting switchboard the whole load of one of the lighting engines may be taken up on the frames for experimental purposes, or current may be taken for any special purpose, as may be required. Arrangements are provided by means of which the field of any machine may be at once excited, if required, from the ordinary

lighting circuit or battery, or by any other machine which may happen to be running at the time on the testing-beds.

The most important point to be ascertained in the economy of a steam-dynamo is the amount of steam consumed by the engine for a given output of energy by the dynamo, or the number of pounds of steam required by the engine per electrical HP.-hour, or per kilowatt-hour, developed by the dynamo. As an engine is more economically worked if fully loaded (two half-loaded engines of the same size requiring more steam than one of them fully loaded), it is of great importance to determine how the consumption per electrical HP.-hour, or per kilowatt-hour, increases as the engine is more lightly loaded. For this purpose tests are often made at three-quarter, half, and quarter load, as well as at full load. The water running out of the condenser or air-pump falls into one of the weigh-tanks in a pit below the level of the floor. In measuring the steam-consumption the weight on the beam is moved along till it overbalances the water. As the tank fills, the beam rises and causes an electric bell to ring, and the observer notes the hour, minute and second on the clock. He sets the weight forward a certain amount, varying between 10 lbs. and 300 lbs. according to the size of the engine and its load, so that the bell will ring again in about a minute. At each observation note is made of the electrical output of the machine in volts and amperes; and, if the water is found to be coming out steadily from the engine, 20 minutes is usually a sufficient length of time to ascertain the steam consumption of the engine for all practical purposes.

Two of the most important quantities to be observed are the current produced by the dynamo, and the voltage at which it is generated. In testing-works, where currents of hundreds of amperes and also currents of small fractions of an ampere have to be measured daily, it is evident that without very carefully designed instruments a large number of these might be necessary, since measurements accurate to one-third per cent., and often even more accurate, are required.

At Rugby the system used for the measurement of continuous currents was designed by Capt. H. R. Sankey, R.E., M. Inst. C.E., and the late Mr. F. V. Andersen, and the adaptability of one of the instruments to measurements widely different in magnitude is remarkable. In measuring current the same instrument is used to measure 2,000 amperes and $\frac{1}{500000}$ ampere, accurate to within one-third per cent., and a similar instrument is used to measure voltage between 1,000 volts and $\frac{1}{1000}$ volt. The system used is a direct deflection method. The current from the machine passes

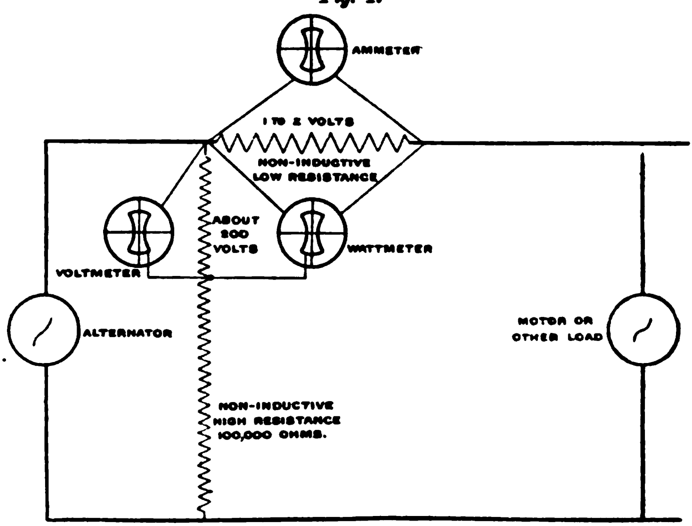
in its circuit through a standard low resistance of a few ten-thousandths of an ohm. The difference of potential between the ends of this resistance, if the resistance be constant or practically so at all temperatures reached in practice, is proportional to the current flowing. Two wires from the ends of this resistance are connected to a galvanometer in the instrument room, and in the circuit is a resistance so calculated that the galvanometer, which reads by light reflected from a small electric lamp, shows amperes direct on the scale, which is 1 foot 8 inches in length, and is divided into 200 parts, each of $\frac{1}{10}$ inch. If the current is over 200 amperes the resistance is so arranged that the scale-reading is one-half or other fraction of the total current. By using main resistances of different capacity and magnitude, currents of largely different value can be easily measured, reading direct in amperes or multiples or submultiples of an ampere. The current taken by the galvanometer is an inappreciable fraction of the whole—about one-millionth. The galvanometers used are of the d'Arsonval type, in which the current passing round a coil suspended in a magnetic field produced by a permanent horse-shoe magnet tends to deflect the coil. The restoring couple is supplied by the fine strip of metal which supports the coil and also leads the current to it, a similar strip below acting as the other conductor. This type is the only one available for the work required, as the large and variable currents dealt with would, by the magnetic field they produce, render useless any other type of galvanometer.

Until recently the measurement of alternating currents was carried out by dynamometers and static voltmeters. This method assumes a "power-factor" of unity in the circuit, so that the current has to be dissipated in resistances or tanks of no appreciable self-induction or capacity. If this were not the case the wattless induction-current would be measured as true current, in phase with the electromotive force, and the efficiency of the machine would appear too high. A complete set of instruments has now been installed, primarily for measuring alternating currents, but which will work equally well for continuous currents, on the system worked out by Mr. G. L. Addenbrooke. They comprise an ammeter, a voltmeter, and a wattmeter, and are all static instruments of the Kelvin quadrant-type. The wattmeter shows true watts, and from it and the apparent watts shown by the voltmeter and the ammeter, the "power-factor," that is, the ratio of the true to the apparent watts, is at once obtained. This method, like that used for con-

tinuous currents, has been designed so that all the instruments are calibrated by the Clark or other standard cell, and at any time any reading on the scale can be reproduced and its true value determined. There is usually considerable induction in the circuits supplied by alternators, on account of the number of partially-loaded transformers which have to be supplied. This makes it necessary to increase the exciting field of the alternator above that necessary on a non-inductive load.

In order to be able to test an engine and dynamo under the conditions of ordinary working, a choking-coil transformer has been installed, by which the power-factor of a non-inductive 100-

Fig. 1.

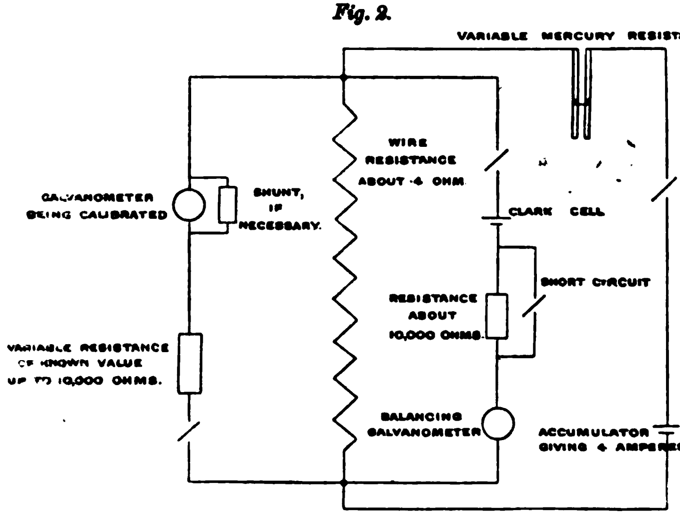


kilowatt load at 2,000 volts may be reduced to about 0·7 by connecting it to the alternator terminals, *Fig. 1.* The coils are arranged so that by putting all in series it may be suitable for a voltage as high as 10,000 volts. The induction is adjusted by variable air-gaps in the magnetic circuit, controlled by means of hand-wheels and screws.

The measurement of voltage in the case of continuous currents is done in a manner similar to that used for the measurement of the current. Two leads from the machine terminals are connected to the ends of a special resistance of 250 ohms. The potential drop caused by the passage of the current through one-hundredth of this resistance, *i.e.*, 2·5 ohms, is indicated on the galvanometer

(similar to the one used for the measurement of current) directly in volts, by adjusting the variable resistance in series with it. If the voltage of the machine be over 200 volts, two or more similar resistances are put in series. For the measurement of low voltages the galvanometer terminals are connected (through the adjustable resistance) directly to the machine terminals instead of using a factor of $\frac{1}{100}$, $\frac{1}{200}$, etc. By alteration of the resistance in series the scale divisions may be made to correspond to $\frac{1}{10}$ volt, $\frac{1}{100}$ volt, or any intermediate fraction. The object of using this system of a derived potential, usually of the value of 1 volt to 2 volts, for actuating the galvanometer, is that by doing so it may be calibrated directly by the standard Clark cell. The

Fig. 2.

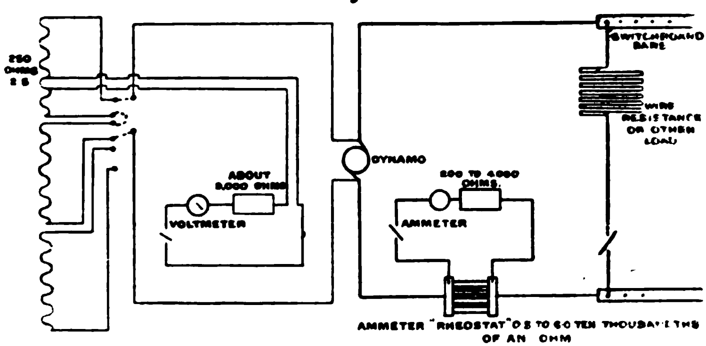


method of calibration employed is shown in *Fig. 2.* The deflection is noted for various values of the resistance in series with the galvanometer when the voltage across the two is equal to that of the Clark cell. This voltage is adjusted by varying the current passing through a resistance, by means of a mercury rheostat, a storage cell being used to supply the current. The Clark cell is in series with a high resistance which is short-circuited in the usual way when an approximate balance has been obtained. If the galvanometer is very sensitive it is shunted by a resistance, the ratio of which to the galvanometer resistance must be known accurately. In addition to the Clark cell a standard ohm resistance is required, with which the current-

measuring resistances are compared, by using a secondary intermediate resistance, the method having been evolved at the time the instruments were designed. This system of continuous-current measurement fulfils the rather unusual conditions met with. It is very accurate, and any reading on the scale can, if necessary, be reproduced in terms of the Clark cell. A diagram of the connections is shown in *Fig. 3*.

The instruments can remain in circuit indefinitely, as they have to do, without alteration due to rise of temperature or other cause. They are frictionless and direct-reading, and a glance at the scales shows at once whether the correct load is on a machine. In this it is superior to the potentiometer method, which requires a "balancing" operation at every reading. It retains the chief recommendation of the potentiometer, in that the calibration of

Fig. 3.

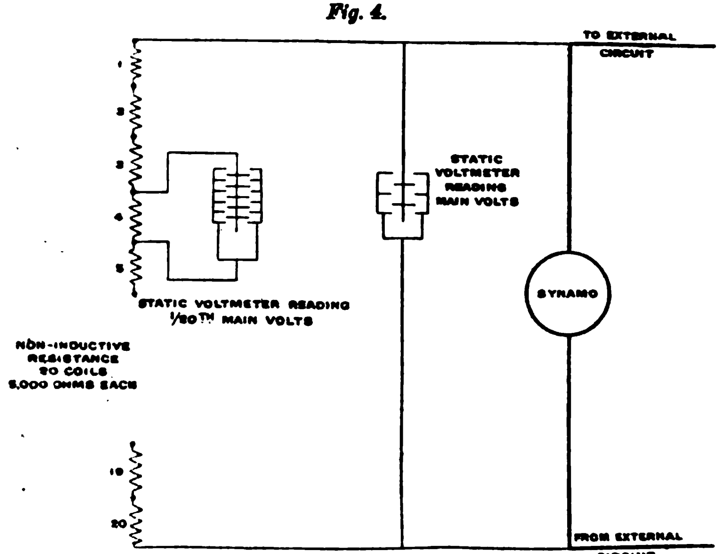


the scales is done by the Clark cell. One of the most necessary requirements is that the apparatus employed be capable of being quickly changed from the circuit of one machine to that of another, and be also able to indicate accurately large and small currents,—conditions which are amply fulfilled by the system employed. To measure the voltage of high-tension continuous or alternating machines, there are two voltmeters of the Kelvin static type, one reading between 1,500 volts and 3,000 volts, and and the other between 70 volts and 140 volts. In conjunction with the latter is a non-inductive resistance of 100,000 ohms, divided into twenty equal parts, across which the full voltage of the machine is put, *Fig. 4*. If the machine generate at 2,200 volts, the lower-reading voltmeter, which is checked by the standard reflecting voltmeter, measures the drop across one of the twenty coils, and reads 110 volts when the direct-reading voltmeter would

read 2,200 volts. A similar additional high resistance of 100,000 ohms has recently been obtained, by which voltages up to 6,000 volts may be measured.

One of the most important quantities to be determined is the indicator-HP. of the engine. For this purpose an indicator is fixed on to each cylinder, and communication with the receiver above is also effected, by means of a three-way cock. The motion for the indicator-drum is derived either from an eccentric on the shaft or from an inclined plane on the cross-head, by a plunger acting through the crank-chamber door. The indicating is done on an electric-bell signal being given from the weigh-bridge room,

Fig. 4.



where bell-pushes are placed near the scales on which the amperes and volts are read. Usually three complete sets from each indicator are taken, the electrical readings, speed, steam-pressure, and vacuum being noted at the same time. Particulars of the test of a Willans non-condensing 360-H.P. engine and Siemens two-pole dynamo are given in the Appendix. The "combined efficiency" is the ratio of the electrical-HP. produced by the dynamo to the indicator-HP. of the engines, the electrical-HP. being the product of the volts and amperes, divided by 746. When an engine is indicated at different loads, it is usual to plot, on squared paper, the indicator-HP. against the output of the dynamo. The results usually fall on a straight line, from which

the efficiency is at once obtained, *Fig. 5.* This diagram refers to a two-pole machine of 225 kilowatts. A similar diagram for a

Fig. 5.

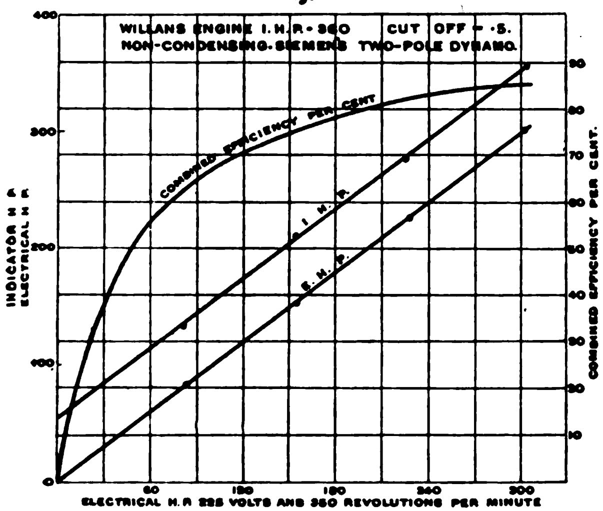
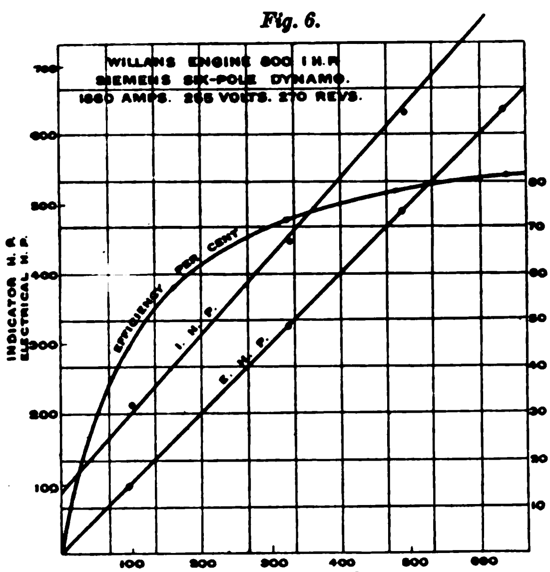


Fig. 6.

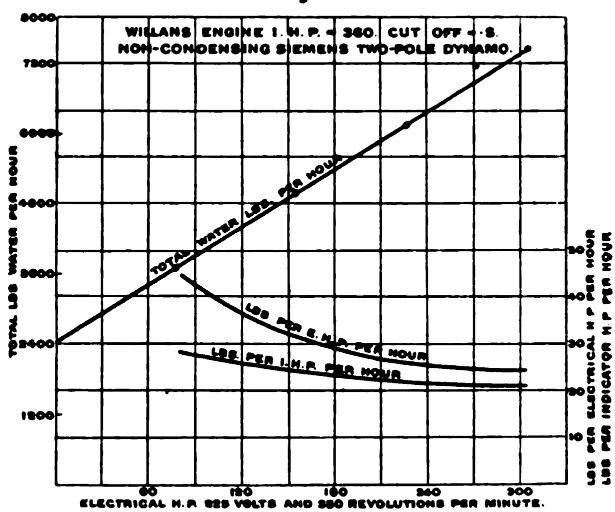


500-kilowatt multipolar machine is shown in *Fig. 6.* It will be noticed that there is very little difference between the losses at

full and at light load in the former, while in the multipolar machine there is a larger loss at full load than at light load. This drop in efficiency of a multipolar machine is caused by increased hysteresis and eddy-currents.

The steam-consumption of the engine is also plotted in a similar manner, the steam used, in pounds per hour, against the dynamo output. This gives at once consumption per electrical-HP.-hour or per kilowatt-hour, and, from the efficiency curve, the consumption per indicator-HP.-hour. The curves shown in *Fig. 7* refer to the compound non-condensing engine of 360 indicator-HP.

Fig. 7.

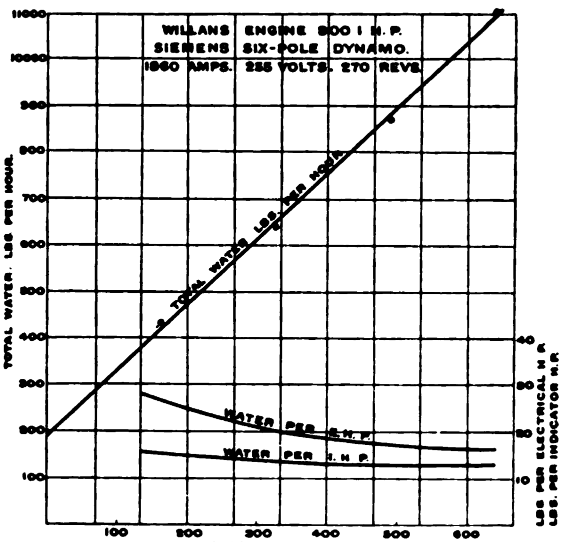


working at 136 lbs. per square inch initial pressure, and those for the 800 indicator-HP. triple-expansion engine working condensing, with 165 lbs. per square inch initial pressure, are shown in *Fig. 8.* It will be seen that these engines have a steam-consumption of 24 lbs. and 17·5 lbs. per electrical-HP.-hour respectively at full load, and of 46 lbs. and 27·5 lbs. per electrical-HP.-hour respectively at quarter load, showing the saving due to the use of the condenser to be relatively greater at low loads. The law established by Mr. Willans, known as the Willans law, viz., "That the curve representing the relationship between the steam-consumption and the indicator-HP. of an engine is a straight line if the engine be governed by throttling the initial steam-pressure," is shown by these diagrams to be applicable

also when referred to the output of the dynamo instead of the indicator-HP. of the engine.

For traction and motor work it is often desirable to alter the cut-off to suit the load, thus securing greater economy at the average load of the engine than is obtained when a throttling governor is used, in which case the cut-off is arranged to give the full output at the full load of the engine, and for the average load the steam has to be throttled, with a slight loss of economy. This is done in the Willans engine by a sleeve with oblique ports, inside which the upper part of the hollow piston-rod works, oblique ports being also cut in the latter. By rotation of this

Fig. 8.



sleeve the cut-off may be altered either automatically or by hand. Mr. Willans found that there was no economy in expanding the steam to more than about twelve times its original volume, so there is no economy in cutting off at an earlier point than that which will give this expansion. The curves shown in *Fig. 9* indicate that by throttling the steam till about half load, and for higher loads making the cut-off later and keeping the initial pressure constant at a little under the boiler-pressure, the economy is greater than it would be were the cut-off made earlier at lower loads. A steam pressure-gauge is usually fixed to show the pressure in the steam-chest of the engine. If the engine be one

having a throttling governor and fixed cut-off, the latter is arranged so that at full load the pressure in the steam-chest is

Fig. 9.

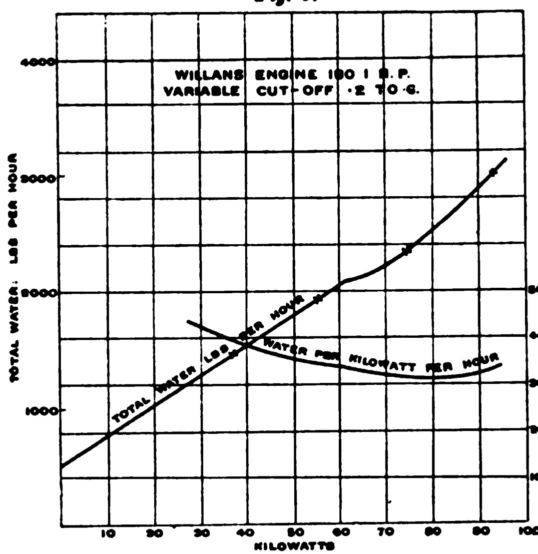
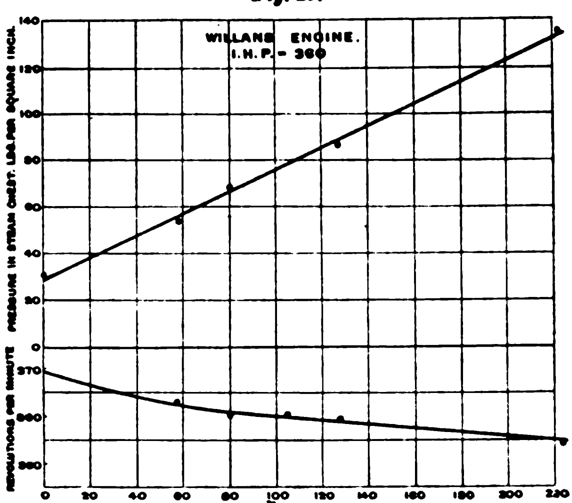


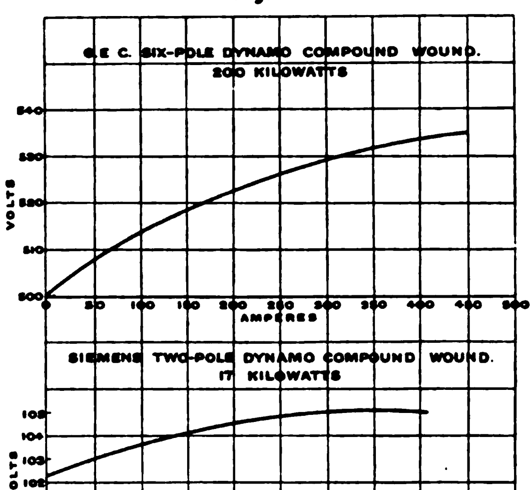
Fig. 10.



slightly{below that which the customer gives as tle boiler pressure, *Fig. 10.*

It has been found desirable to test all pressure-gauges and indicator-springs used. The apparatus employed for this purpose consists of a vertical cylinder of copper partly filled with water, which is acted on by steam pressure from the boilers, and is in connection with a small ram of $\frac{1}{10}$ square inch in cross-section. This ram is loaded with 1 lb. weights, every 1 lb. representing a pressure of 10 lbs. per square inch when the ram is just balanced. The balance is obtained by allowing steam to escape by a needle-valve. By adjusting this valve and the inlet-valve the pressure may be kept nearly constant at any desired amount, and the reading on the gauge is noted when the ram is just

Figs. 11.



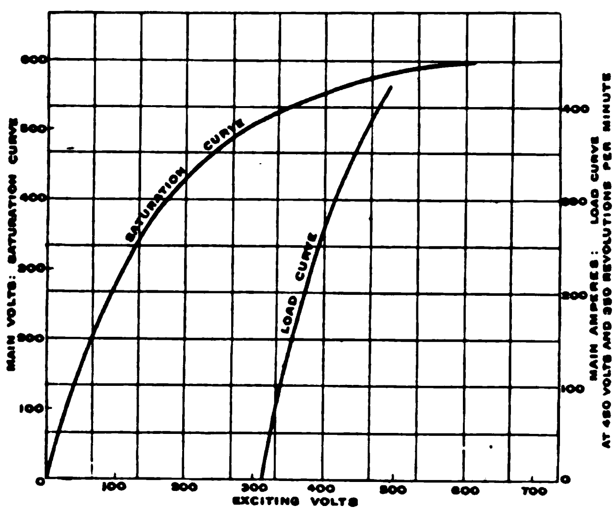
balanced. There is an attachment to which an indicator is fixed for testing indicator-springs, which are thus tested at their working temperature.

Many dynamos for traction and motor work are compound-wound, to maintain a constant voltage automatically, or to raise the voltage as the load increases. For private lighting an increase of 2 per cent. or 3 per cent. is sufficient. In *Figs. 11* is shown the compounding of a 17-kilowatt dynamo, which is in use in a private installation; and also the compounding of a 200-kilowatt traction generator, the voltage at no load being 500 volts and at full load 535 volts. For traction work the machines are usually

over-compounded about 10 per cent. to compensate for the voltage drop in long feeders.

The saturation-curve of the magnets of a dynamo is shown in *Fig. 12.* It will be seen that with all external resistance cut out of the exciting circuit the machine gives 600 volts. The load-curve is also given, showing the relation between the main amperes and the exciting volts when the main voltage is kept constant at 480 volts. The two curves show the portion of the saturation-curve which is used over the range of the load when the main voltage is kept at 480 volts. This is an important point in the design of the machine.

Fig. 12.

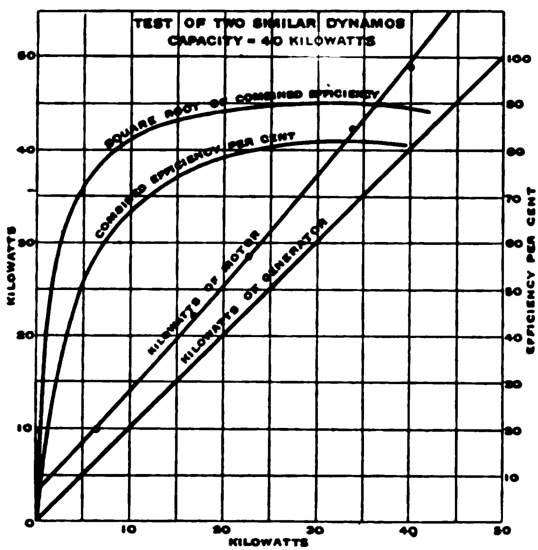


At the request of the dynamo-makers, tests were recently carried out on two identical 40-kilowatt dynamos. The two armature shafts were coupled together and one of the machines was run as a shunt motor from a separate source of supply. The other was run as a dynamo, the load being taken up in the usual way on wire frames. The results show a combined efficiency of about 81 per cent. or an efficiency of 90 per cent. for each machine, if it is assumed that the two machines have the same efficiency, *Fig. 13.*

A Froude hydraulic brake, made by Messrs. Mather and Platt, of Manchester, is used for measuring brake-HP. It absorbs the power of the engine by churning water which passes through it.

The power is measured by hanging the required number of 80-lb. weights on the end of a lever, the smaller adjustments being made by a jockey-weight. By adjusting the cocks controlling the inlet and outlet of the water, the beam is made to balance horizontally. From the weight on the lever, the distance of the weight from the centre of the shaft, and the speed of the engine, the brake-HP. is obtained. The brake is capable of absorbing about 700 HP. at 250 revolutions per minute, and will keep the beam horizontal automatically if required.

Fig. 13.

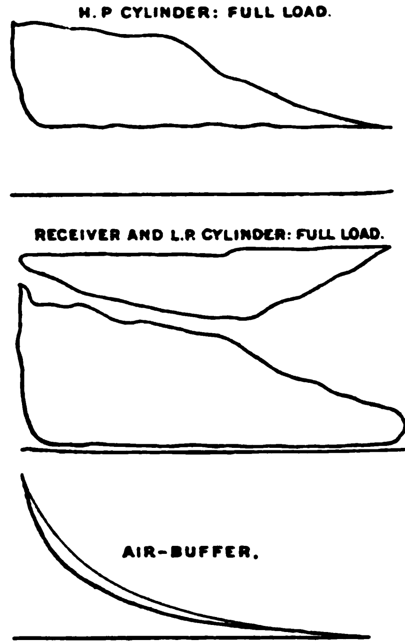


In conclusion the Author desires to thank the Directors of Messrs. Willans and Robinson, Ltd., for permission to publish the information contained in the Paper and to take the photographs which accompany it. His thanks are also due to Mr. Low, the head of the testing department, and to one or two friends who have assisted him in the preparation of some of the diagrams.

The Paper is accompanied by fifteen diagrams, from which the Figures in the text have been prepared; also by nineteen photographs and the Tables given in the Appendix.

[APPENDIX.

Figs. 14.



APPENDIX.

Test of a Willans Compound Non-condensing Three-Crank Engine of 360 I.HP., and Siemens Two-Pole Dynamo.

L.P. cylinder, 1 foot 8 inches diameter; piston area, 209·4 square inches; stroke, 9 inches; area of air-buffer piston = 0·55 that of L.P. piston, *Figs. 14.*

Table I.

Size, III's. Cd. Engine No. 3011. For Eccleston Place.

Date, April 26, 1900. Present, Messrs. Newington, Low and Templer.

Diagram.	Cylinder.	Planimeter.		Area.	Length.	Scale.	M.P.	Constant.	M.P. on L.P. Cylinder.
		Start.	Stop.						
F.M.G. 1, 2, 3 .	H.P.	0	5·13	5·13	18·07	150	42·60	0·487	20·75
Full load . . .	R.	5·13	8·94	3·81	18·15	50	10·50	0·449	4·71
Non-condensing .	L.P.	8·94	18·24	9·33	18·15	50	..	..	25·71
136 lbs. pressure in steam chest.				Total M.P. referred to L.P.C.					51·17

Diagram.	Amperes.	Volts.	Revs.
F.M.G. 1	1003·0	225	351
„ 2	1002·0	225	351
„ 3	1003·0	225	351
	1002·6	225	351

$$\frac{1002 \cdot 6 \times 225}{746} = 302 \cdot 2 \text{ E.HP.}$$

$$\frac{209 \cdot 4 \times 9 \times 3 \times 51 \cdot 17 \times 351}{12 \times 33{,}000} = 355 \cdot 7 \text{ I.HP.}$$

Efficiency = 85 per cent.

TABLE II.—CONSUMPTION TRIAL.

Engine No. 3011. Size, III's. For Eccleston Place.

Barometer, inches. Type, compound.

Date, April 26, 1900. Present, Messrs. Newington, Low and Templer.

Water collected. Non-condensing.

Weight in Lbs.	Time.			200-Lbs. Interval.		Amperes.	Volts.	Remarks.
	Hrs.	Mins.	Secs.	Mins.	Secs.			
6,100	10	38	56	1	39	1,005	225	Steam pressure, 136.
6,300	10	40	35	1	39	1,000	225	Revolutions, 351.
6,500	10	42	11	1	36	1,002	225	Vacuum.
6,700	10	43	49	1	38	1,003	225	Cut off = 0·5.
6,900	10	45	25	1	36	1,002	225	I.HP. = 355·7.
7,100	10	47	3	1	38	1,002	225	E.HP. = 302·2.
7,300	10	48	42	1	39	1,002	225	M.P. = 51·17.
7,500	10	50	20	1	38	1,002	225	Efficiency = 85 per cent.
7,700	10	51	59	1	39	1,002	225	Mean E.HP. = 302·1.
7,900	10	53	36	1	37	1,003	225	K.W. = 225·4.
8,100	10	55	15	1	39	1,004	225	Water consumed—
8,300	10	56	53	1	38	1,003	225	Per I.HP. per hour = Lbs. 20·6.
8,500	10	58	31	1	38	1,002	225	Per E.HP. per hour = Lbs. 24·2.
8,700	11	0	11	1	40	1,002	225	Per K.W. per hour = Lbs. 32·5.
8,900	11	1	50	1	39	1,001	225	
9,100	11	3	29	1	39	1,000	225	Cards = 1, 2, 3.
3,000	in	24	33			1,002	225	Shunt amperes = 9·4.
		24·55						Volts across field = 160.
7,330 lbs. per hour.								

TABLE III.—SUMMARY OF CONSUMPTION TRIAL.

26 *April*, 1900.

Name of Engine, Eccleston Place. No. 3011. Size, III's. Cd.

Load.	Pressure in Steam Chest.	Cut Off.	Mean Pressure.	Vacuum in Exhaust Chamber.	Revs. per Minute.	Consumption of Steam in Pounds of Feed-Water per Hour.						Efficiency.			
						I.HP.		B.HP.		E.HP.		Brake.		Combined.	
						Actual.	Guaranteed.	Actual.	Guaranteed.	Actual.	Guaranteed.	Actual.	Guaranteed.	Actual.	Guaranteed.
Full	136	0·5	51·17		351	20·61	20·5			24·26	24.2			Per Cent. 85·0	Per Cent. 85
¾	110	0·5	39·93		349	22·12				27·0				81·9	
½	85	0·5	29·89		350	23·67				32·26				73·3	
¼	60	0·5	18·74		350	28·4				45·56				62·3	
Exciting Light	31	0·5	6·10												

This Form to be filled up for every Engine with which a Consumption or Guaranteed Consumption Trial has been made.

Signature of Head of Testing Dept. ______________________

TABLE IV.—FULL LOAD. HEATING TRIAL.

Size, III's. Type, Compound. Engine No. 3011. For Eccleston Place.

Siemens Dynamo No. 5050 A. ________Exciter No.________.

Date, April 26, 1900. Present, Messrs. Newington, Low and Templer.

Vacuum.	Steam Chest Press.	Revolutions.	Amperes.		Volts.	Time.	Ohms in Field.
			Main.	Shunt.			
	145	344	1,050	9·0	218·0	8.0 A.M.	9·0
	137	350	1,000	9·5	226·0	8.30 „	9·0
	136	350	1,000	9·4	226·0	9.0 „	8·0
	136	351	1,000	9·4	225·0	9.30 „	7·7
	136	350	998	9·5	226·0	10.0 „	7·4
	136	351	1,002	9·5	225·0	10.30 „	7·2
	136	350	1,000	9·5	224·0	11.0 „	7·0
	136	350	1,000	9·4	224·0	11.30 „	7·0
	135	350	1,000	9·4	225·0	12 NOON	7·0
	135	350	1,000	9·4	224·0	12.30 P.M.	7·0
	135	350	1,000	9·4	225·0	1.0 „	6·8
	135	351	1,000	9·5	224·5	1.30 „	6·4
	135	350	1,000	9·5	224·0	2.0 „	6·3

Temperatures.		°F.
Armature	Eng: End . . .	130
	Com: End . . .	128
	Magnets	100
	Air	69

SECT. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

The Foundations of the Paris Metropolitan Railways.

WEISS.

(Comptes Rendus de la Societé de l'industrie Minérale, 1902, p. 8.)

The subsoil of Paris is in parts extensively honeycombed with subterranean quarries which have been worked both for building stone and plaster from the Roman period until near the close of the nineteenth century. In all cases the method has been pillar working, leaving extensive hollow spaces which, when the roof is sound, may retain their form indefinitely; but when, by reason of infiltration or weakness of the pillars, falls are set up they go on continuously forming bell-shaped cavities, until finally the surface may fall in without previous warning. Accidents of this kind have occurred within the past two years, when three men were buried at Pantin by a sudden yielding of the ground under their feet, owing to the collapse of an old *fontis* or bell pit. Some of the lines of the new underground system, namely, the No. 2 southern circular, the No. 4 transverse line, No. 6 line, and the projected line, Palais Royal-Place de Danube, passing through the old plaster quarries of the Buttes Chaumont which have completely fallen in, traverse the old quarry regions, and require special consolidation of their foundations. One of the first of these (No. 2 south), about 2½ miles long, a very considerable number of special works have been necessary, but they are mainly reducible to two types, namely, those in which the quarry is sound overhead, and those where there have been extensive falls of roof. In the former case a gallery 2 metres wide is driven parallel to the centre line of the tunnel, and pillars of masonry 4·2 metres transverse breadth by 1·2 metres long in the direction of the line spaced 4 metres apart, are built up to the roof on each side to support the ground below the tunnel invert. This applies to the ordinary double line tunnel with a maximum width of 8·6 metres at the springing of the roof; but below the stations where the tunnels are 18 metres wide a gallery is driven below each of the abutment walls in addition to the central one, and the pillars are extended on either side in five rows, a central small one and two broader ones on either side, giving a total transverse breadth supported of about 14·2 metres, the length and spacing being the same as in the narrower

parts of the line. In the second case where the roof has fallen and the upper strata are broken and disturbed, three series of shafts, 1·2 metres in diameter spaced 5 metres apart in the direction of the line and 3¾ metres transversely, are sunk to the quarry bottom and are then filled up with concrete, above which is laid a floor of armoured concrete to form the foundation of the invert. In the station tunnels in addition to two central series of round pillars, others, two metres square, placed 6 metres apart and connected by semicircular arches, are placed below the footway of the side wall on either side. These works being part of the substructure are carried out at the cost of the City of Paris under the charge of Mr. Wickersheimer, Engineer-in-Chief. They have been let in six contracts at a cost of £64,400, or about £16,000 per mile including the stations, while the actual cost of the railway to be built above them is estimated at an average of £192,000 per mile. The work, which will require about 12 months for its completion, is about one-third finished, an average of 500 men being employed daily, and, in spite of its essentially dangerous character, no serious accident has happened during four months' work. It is expected that the ground will be ready for the commencement of the railway works in June, 1902.

H. B.

Electric Tramway from Grenoble to Chapareillan.

PIERRE DE MÉRIEL.

(La Nature, 23 November, 1901, p. 407.)

The generating station for this tramway line is situated at Lancey, on the left bank of the River Isère, at a distance of 7·45 miles from Grenoble, and about 2 miles away from the line of rails. The fall which furnishes the motive power is 1,476 feet in height, and the water is conveyed to the works in an iron riveted pipe, under a pressure of 45 atmospheres. In consequence of the enormous pressure, it has been necessary to design special valves to admit the water to the three turbines, each of which develops 340 HP., at a speed of 325 revolutions per minute. There are three generators, which each furnish a continuous current of 417 amperes, with a difference of potential of 600 volts. The current is distributed by means of six overhead conductors of bare copper, varying in section between 0·194 square inch, and 0·1 square inch, carried on metal posts, with double bell porcelain insulators; while a copper cable of 0·194 square inch in section is coupled with the tramway metals, which act as conductors for the return current. Vignoles rails, weighing 50 lbs. to the yard, are used for the sections for lighter traffic, and Broca rails of 80 lbs. to the yard for the heavier traffic. The line has been laid as far as practicable along the existing roads, and has a total length of

about 26¾ miles. A plan and section are given of the line, and views of the station at Crolles, the generating station at Lancey, and the passage of the tramway through the village of Touvet. There are also descriptions of the motors and rolling-stock.

G. R. R.

Corrosion of Steel Rails. J. W. Post.

(Organ für die Fortschritte des Eisenbahnwesens, 1901, p. 268.)

The Author is of opinion that rails exposed to the direct action of sea-water, especially in tropical countries, should be heavier than the normal sections, and in particular the lower flange. He mentions the case of a rail that had been down 10 years on a line in Sumatra, at the Emma Harbour, and from his measurements he found that the weight had diminished from about 51½ lbs. per yard to 30 lbs. per yard, at the rate, namely, of about 2 lbs. per yard per annum, or 4 per cent. of the original weight. The head had been 53 millimetres (2·1 inches) wide when new, and had been reduced to 42 millimetres (1·65 inches). The corrosion of the foot of the rail was very great; it had been diminished in width from 90 millimetres (3·54 inches) to 63 millimetres (2·48 inches) while the original thickness of 8 millimetres (0·31 inch) had been reduced to an average of one-fourth of this, that is, to less than $\frac{1}{10}$ inch.

J. G.

Experimental Runs with Locomotives. von Borries.

(Organ für die Fortschritte des Eisenbahnwesens, 1901, p. 208.)

These experiments were carried out principally with the object of comparing the performances of three classes of engines:—(*a*) A 4-coupled 8-wheeled 4-cylinder compound; (*b*) an engine of similar build to that of (*a*) but having two cylinders and using steam superheated to about 300° C.; (*c*) an older type of 4-wheeled 8-coupled 2-cylinder compound.

The run in each case was for a distance of about 124 kilometres (77½ miles) and back, the load consisting of from seven to nine coaches, according to the supposed capacity of the engine.

The fire grate area was the same for the three engines, 2·3 square metres (24·7 square feet), the heating surfaces were 118 square metres (1,270 square feet) for the 4-cylinder compound, 106 square metres (1,140 square feet), with 28 square metres (301 square feet) of superheater surface for the 2-cylinder high-pressure engine, and 125 square metres (1,345 square feet) for the 2-cylinder compound.

The boiler pressures in the three engines were 14 atmospheres

(200 lbs. per square inch) for the 4-cylinder compound, and 12 atmospheres (170 lbs. per square inch) for the two others.

The 4-cylinder compound proved the most powerful and also the most economical engine. The running was remarkably smooth, causing less fatigue to those in charge of the engine, and therefore also less wear and tear on the parts of the machinery, than in ordinary locomotives.

The 2-cylinder high-pressure engine ran somewhat hard and jerky, but it is expected that this may be improved by having longer bearing springs and by moderating the initial steam pressure.

The trips were run at about 55 miles per hour, the average performances of the three engines being respectively :—(*a*) 878·9 HP.; (*b*) 808·9 HP.; and (*c*) 754·5 HP.

The horse-power per hour per kilogram (2·2 lbs.) of coal burned was in the three cases as follows :—(*a*) The 4-cylinder compound, 0·95 HP.; (*b*) the 2-cylinder high-pressure, 0·87 HP.; (*c*) the 2-cylinder compound, 0·86 HP.

The weights of the three locomotives in the order as mentioned above were 53·0 tons, 52·3 tons, and 47·6 tons, and the powers exerted in pulling the trains of coaches per ton weight of locomotive were 9·26 HP., 8·87 HP., and 8·91 HP.

The 2-cylinder high-pressure and the 2-cylinder compound engine were practically equal in general efficiency.

J. G.

Heating of Railway Carriages by Steam. K. SPITZER.

(Organ für die Fortschritte des Eisenbahnwesens, 1901, p. 182.)

Engineers on the Continent have not yet been successful in heating trains, consisting of say about twelve coaches, in such a manner that the temperature is uniform from end to end of the train. The main steam-pipe from the engine is about 40 millimetres (1·6 inch) in diameter with branches to radiators, and, after heating these radiators, the steam escapes into the outer air.

By this method the time taken to heat the train is very long, and frequently the last few coaches are scarcely heated at all, while those in front may be inconveniently warm. The principal means of reducing the temperature in any particular compartment consists in shutting off steam from the radiators, but this does not prevent heat from continuing to be given off by the still hot pipes.

The Author proposes to use an auxiliary steam-pipe going direct from the engine to the last carriage, and so forming with the original radiators and pipes a closed circuit fed by steam from the engine. The train would thus be heated from both ends, requiring less time and also making the temperature more uniform throughout.

On this system every carriage would be fitted with a line of pipes with radiators along one side and a simple pipe along the other. While it might be preferable to have all the carriages of a train with the simple pipes to the same side, practically it would make very little difference to the heating, and the coupling would in fact be simpler than it is now.

For ventilation, and in order to avoid the stuffiness that accompanies heating by radiators, the Author proposes to provide openings in the floor just underneath the large pipe under the seat. These openings are to be under the control of the passengers to be opened or closed at will, while the steam-pipes are never shut off from the engine.

J. G.

Theory of Masonry Arches. GNUSCHKE.

(Zeitschrift für Bauwesen, 1901, p. 607.)

In an earlier Paper the Author had shown that the theory by which masonry arches were calculated as if they were inverted forms of suspended cords, not, of course, perfectly flexible, was inapplicable to arches as actually constructed, and that, when the effect of the backing was taken into account, the semi-circular and elliptic or basket-handle arches were found, contrary to the general understanding, to be the correct form for the conditions of equilibrium.

According to the Author's theory, it is not a necessary rule that the thrust should increase from the summit of the arch to the springing; the general problem is also entirely changed. Instead of taking the load as given, and determining from it the proper form of arch, the question is, having given the outline of the soffit of the arch and the external loading, to find the form and dimensions of abutments and backing. If the depth from the soffit to a given horizontal line—say the upper surface of the roadway—be supposed to represent the intensity of the loading, and if it be assumed as a condition of the design that the thrust of the arch is to be constant from summit to springing, then the outline of the soffit will, on the Author's theory, be of a shape closely approximating to an ellipse.

Selecting the horizontal line above mentioned as the X axis and a vertical line through the centre of the arch as the Y axis, also putting ρ for the radius of curvature of the soffit, the conditional equation is—

$$y\rho = m^2,$$

m being a constant. Taking the intensity of loading at the crown as unity, the radius of curvature at the crown, say r, will be equal to m^2, and the value of r may be fixed upon as the characteristic or modulus of each curve.

To plot the curves by Cartesian co-ordinates, the values of Y can be easily obtained, but the expression for X involves an elliptic integral. The Author shows how this may be avoided by mechanical quadrature; he also gives the detailed method of using elliptic integrals and their moduli.

W. B.

Masonry Bridge across the Petrusse Valley, Luxemburg.

(Engineering, 24 January, 1902, p. 124.)

A remarkable masonry bridge has recently been erected at Luxemburg across the valley of the Petrusse. It is an elliptical arch of 277·6 feet span in the clear, with a versed sine of 53·15 feet. The depth of the arch-ring is 4·72 feet at the key, and 7·08 feet at the springing. The weight of the roadway is transferred to the main arch by open spandrel arching. The structure consists really of two separate arches, each 17·48 feet wide and 33·22 feet apart, between centres, the space between the arches being bridged over by a platform of armoured concrete which supports the roadway. The total width between parapets is 55·5 feet. The arch was built in three rings, and each ring was divided into several distinct sections, wedged apart till the whole of the weight was in place.

On removing the centres the settlement at the crown was found to be only 0·236 inch.

C. H. M.

Concrete Bridge over the Nalon at Las Segadas, Spain.

J. E. Ribera.

(Revista de Obras Publicas, 1901, p. 139. 2 Plates.)

The high road which is being constructed from Oviedo to Pola de Lena by way of Riosa, crosses the valley of the River Nalon at Las Segadas, and the design of the bridge over this river, which was approved in 1898, offers several points of interest. It will be the longest single span in Spain, will be constructed of concrete, and the concrete arch will be in two halves, pivoted at the haunches and crown. The bridge of next longest span is the San Martin of Toledo, with 132 feet. The Author cites bridges of concrete which have given satisfaction in other European countries, and then proceeds to calculate the stresses in the bridge under discussion, and the method in which the dimensions of the various parts were decided. The vertical height of the arch measured from a horizontal line, passing through the fulcrums on the skew-

backs to the centre of the knuckle joint at the crown is 14·76 feet.

Rows of piles were driven into the bed of the river, and upon these a wooden framework was erected which supported the centering, and upon this the concrete arch was formed. The concrete portion is 3·6 feet deep at the crown and at the springing, and 4·6 feet deep at the haunches. The estimated cost of the whole work is £3,845.

E. R. D.

History of Bridge Building and Limiting Spans of Bridges.

Prof. Weyrauch.

(Zeitschrift für Bauwesen, 1901, p. 466.)

The first bridge concerning which there exists any definite information, was built over the River Euphrates, the structure consisting of stone piers and timber beams in spans of about 13 feet. The Romans made great advances in bridge-building, attaining to spans of 117 feet. From the time of the Romans up to the end of the eighteenth century the advances made were irregular, the two most noteworthy structures being a stone arch of 236 feet span built in Italy in 1377 and the Limmat timber bridge built in 1779 and spanning nearly 400 feet.

The first iron bridge was built in 1776 in the form of a cast iron arch, and this continued to be the type of all fairly large-span bridges for about fifty years, until, in fact, wrought iron was rolled into plates and bars and built up into girders. Suspension-bridges were also developed in the beginning of the nineteenth century, and have been regarded since the second decade as the special type for very large spans.

The Author considers the bearing of theory on the increase in the spans of bridges and on the question of limiting spans. As a basis for the comparison of the three types, the girder, arch, and suspension-bridge, the materials of construction are assumed as wrought iron or mild steel for the first two with an ultimate strength of 3,500 kilograms to 4,500 kilograms per square centimetre (22·2 tons to 28·6 tons per square inch), and cast steel wire for suspension-bridges with a strength of 12,000 kilograms per square centimetre (76·2 tons per square inch). Assuming a dip of one-third of the span and a factor of safety three, the limiting span for a suspension-bridge with wire of the strength given above is 3,730 metres (2⅓ miles).

The Paper contains several appendixes dealing with special points in theory.

W. B.

Concrete Facing for Dam Slopes. L. Schlegel.

(Ingeniøren, Copenhagen, 1901, p. 405.)

A causeway across Sebbesund at Nibe in Denmark, about 2,500 feet long, with a wood bridge in the middle about 100 feet long, was taken over by the local authorities in June 1881, after having been maintained by the constructor for the first year. It is 24 feet wide at the top, which is 8 feet above ordinary water-level. The slopes are 2 to 1 on the north-east side, where the worst sea was expected; and 1½ to 1 on the south-west. They were pitched with granite rubble, backed by a layer of shingle, up to 2½ or 3 feet above water-level; and thence upwards were covered with turf. The bottom was hard at the land ends, but soft in the fairway. During the first year the stone pitching suffered badly, and a great deal had to be done over again; and in the first winter after it had been taken over, the causeway itself was so greatly damaged by the waves that the traffic was almost interrupted; over the soft bottom some parts of the road subsided so considerably that the stone pitching did not reach much above the surface of the water. On the Author's proposal, the interstices of the rubble pitching were then filled up with cement mortar; and the whole was faced, up to 6 feet above water-level, with 3 inches thickness of concrete, mixed on the spot, and spread in separate panels so as to allow of expansion. The work occupied three to four years, being carried on always at the part most exposed at the time. The facing has now lasted 20 years, without having required any repairs of importance. Last winter (1900–1) it withstood a run of drift ice, which in ten minutes covered the whole causeway for a length of 400 feet with 6 to 8 feet of ice. The drift came from the south-west; and though the parapet walls were razed, the concrete facing of the slope of 1½ to 1 sustained no injury, as the ice slid steadily up its smooth surface.

The same plan has since been followed by the Author with equal success at several other places, including two dams in the Lim Fjord east of Aalborg. At one of these, after the lower part of the pitching with granite in cement had been carried out, it was desired to widen the top of the dam; which was accomplished by carrying the slopes up steeper and steeper to the top, where they were about 1 to 1. The thickness of the concrete facing was 4 inches. When care is taken to prevent the filling under the concrete from being washed out, the Author considers a 3-inch facing of concrete will form a good protection for slopes in the inland navigable waters of Denmark.

A. B.

New Dredgers for the Estuary of the Seine. DANIEL BELLET.

(La Nature, 30 November, 1901, p. 420.)

Great changes have been made in the recent construction of dredgers to comply with modern requirements. They must be good sea-going vessels, capable of transporting themselves by their own steam, of carrying away the materials they have dredged up, and of working at great depths. As types of these modern vessels the Author describes and illustrates two dredgers recently built by Mr. Satre, of Lyons, for use in the Seine between Rouen and Havre. They have twin four-bladed screw-propellers; their speed on trial was 8 knots when fully laden, and their sea-going qualities were well tested in the rough passage round by Gibraltar. These boats are 197 feet in length, with a beam of 34·4 feet over all, and they are divided into ten water-tight compartments by eight bulkheads. The engines are of 540 indicated HP., with two Belleville boilers and tank space for 75 hours' supply of fresh water. The arrangements for dredging are very simple, consisting in the main of a suction-pipe, capable of being raised or lowered, and of working at an extreme depth of 42·6 feet. The suction-pipe has a flexible joint connecting it with the two centrifugal pumps, which furnish the dredging power. The pumps can raise 654 cubic yards of mud in 38 minutes. The excavated materials are conveyed into fourteen tanks, seven on either side of the hold, each of which has a discharging outlet, which is opened by a special steam-winch driven by means of steam from an auxiliary boiler, which also supplies the engine for the dynamo.

G. R. R.

Fixing a 120-ton Sheer-legs at the Port of Havre. C. DANTIN.

(Le Génie Civil, vol. xl., 1901, p. 17.)

The Chamber of Commerce of Havre having decided to install a 120-ton hydraulic sheer-legs, this Paper describes the construction of the crane and the methods employed to fix it.

The type chosen was of three legs, the back leg being moved by a hydraulic ram mounted on an inclined bed. The two upright legs are fixed on the quay wall, and the movement of the ram permits a range, with the full load suspended, of 9 metres (29·8 feet) in front, and 11 metres (36·1 feet) behind the edge of the quay. The lifting is effected by a hydraulic ram hung from the joint of the three legs, the height of lift being 16 metres (52·4 feet). The legs are lattice girders of rectangular section, the front legs being 45·7 metres (150 feet) high, and weighing 20·7 tons each, the back leg being 37·94 metres (124·4 feet) long, and weighing 14·8 tons.

The hydraulic power is furnished by a 4-cylinder pump running at sixty revolutions per minute, and driven by a motor running at 500 revolutions per minute, the reduction being effected by gearing. When lifting heavy loads two of the pump cylinders are disconnected. The motor can be varied in speed, being worked by current at either 275 or 550 volts. The speed of lift for a load of 120 tons is 1·5 foot per minute.

The lifting of the legs and putting into place was effected by the aid of a floating crane, and details are given of the means adopted, two plans and seven photographs showing the various operations. A sheet of five figures illustrates the details of construction of the sheer-legs.

H. L. J.

Haulage by Motor Wagons. Bert.

(Annales des Ponts et Chaussées, 1901, p. 39.)

The Author in this Paper compares the cost of haulage in the City of Paris by horses and by motor wagons. The lowest price for haulage by horses was 4 francs (3*s.* 4*d.*) per ton, and the charge for a horse, wagon and driver was 15½ francs (13*s.*) per day, which equals 2·7 francs (2*s.* 3*d.*) per ton. The charge for a 2-HP. motor wagon, carrying up to 5 tons, including the driver, was 20 francs (16*s.* 8*d.*) per day.

A description is given of the various types of motor wagons which the Author investigated during his inquiries, particulars being given of the gross and effective weights, HP. of motors, speeds, consumption of fuel or current, and cost. The types described are:—(1) Steam tractors: Scotte, Le Blant, and de Dion and Bouton; and steam wagons: Serpollet and Chaboche. (2) Petrol wagons: Panhard and Levassor, Peugeot, de Dietrich, Pantz and Cambier. (3) Electric-motor wagons: Compagnie Française, Krieger, Mildé, Jenatzy, Say, Postel-Vinay, Amiot-Peneau, and Schültze. (4) Compressed-air wagon: Molas Lamielle and Tessier.

A consideration of the price of the wagons then follows, the Author giving formulas for roughly obtaining the price of each of the four systems. The price per ton effective varies within the following limits for loads of 1 to 5 tons:—

Steam wagons	18,000 to 4,000 francs (£720 to £160).
Petrol „ . . .	8,000 to 4,800 francs (£320 to £192).
Electric „ . . .	12,000 to 5,600 francs (£480 to £224).
Compressed-air wagons	6,000 to 4,400 francs (£240 to £176).

The sections following deal with (1) a comparison of the dead weight per ton effective for each system; (2) the degree of utilization of energy; (3) the cost per kilometric ton (0·62 mile); (4) a comparison between the various types of wagons.

In conclusion the Author considers: (1) That at the present price of fuel motor wagons can with difficulty compete with horse wagons. (2) That animal traction is more economical for light weights. (3) That steam wagons are only cheaper for weights above 2½ tons. (4) That electricity can only be advantageously employed when circumstances permit of the economical production of current. (5) That the excessive price of spirit hinders the development of petrol wagons, which could work advantageously on loads of less than 2½ tons.

As matters stand mechanical traction can only compete against horse traction where the loads to be moved are heavy, or where speed is of more importance than economy.

H. I. J.

Vibrations in Automobiles. F. Drouin.

(Le Génie Civil, vol. xl., 1901, pp. 92 and 106.)

Automobiles are subject to vibrations which proceed from two causes, viz., the inequalities of the road, and the movements of the engine. The Author proposes in this Paper to deal with the latter cause only, the former being common to all vehicles.

Reciprocating engines, especially single-acting, of necessity tend to give rise to vibrations, and balancing can only be obtained at the sacrifice of complication in the mechanism. Upon vehicles the superfluous strains causing vibration appear under two distinct forms: (1) Strains of inertia proceeding from parts with either a reciprocating or circular movement; (2) direct reactions due to the transmission of power.

The forces of inertia causing vibrations are of five distinct kinds, due to: (1) Forces in the direction of movement of the piston; (2) forces at right angles to this movement and to the axle, due to the connecting-rod; (3) centrifugal forces (cranks, balances, etc.); (4) couples due to the preceding forces; (5) couples due to the inertia of the fly-wheels.

The Author investigates various types of engines with from one to six cylinders, and the means adopted to minimize vibrations; giving details of and describing a Delahaye horizontal engine, 4-cylinder Panhard and Levassor, 2-cylinder Gobron and Brillié, 2-cylinder Crozet, Lanchester engine and Bardon engine. He considers that the equilibrium obtained by a number of cylinders greater than six presents little practical interest, the only benefit obtained resulting from a reduction of the couple due to the inertia of the fly-wheels. Far greater benefits result from disposing the cylinders around the axle, by which means the efforts in the direction of the movement of the piston can be completely balanced.

The springs of the vehicle itself give rise to great vibration, particularly when the vehicle is at rest, being more pronounced in

single-cylinder engines of low speed. The increase in the number of explosions reduces the vibration due to this cause.

Steam automobiles are less liable to vibrations than internal-combustion motors, the effort being more constant and the parts, in comparison with engines of equal power, being much lighter.

Twenty-five figures in the text illustrate the Paper.

H. I. J.

Regulations for Boiler Attendants in Saxony.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1901, p. 839.)

At starting the fire must not be forced, the draught being regulated so that the boiler is not heated too quickly, and during firing up the attendant must satisfy himself that the safety apparatus and gauges are in working order. The water gauges, &c., are to be frequently tested by opening the cocks and the pressure gauge by shutting off the steam pressure so as to bring the pointer to zero. Safety-valves are to be lifted several times daily to admit of the steam escaping, and the loading must not be increased even although the safety-valve may blow off before the highest allowable pressure is reached. Cocks and valves are not to be opened or closed suddenly.

The water is not to be allowed to sink below a certain level; and if through any cause this limit is exceeded the fire must be at once drawn. During meal times when work is stopped, and also at the end of the day, the boiler is to be fed with water and the draught diminished. At night, before leaving, the attendant must draw the fire, rake the grate clear, and close all draught-plates, fire- and ash-doors.

So long as the boiler is generating steam the attendant must remain on duty, and is not allowed to hand over the care of the boiler to any other person without the consent of his employers or their representatives.

There are also regulations regarding the periodical cleaning and inspection of furnaces and boilers, the presence of unauthorized persons in boiler-houses, and the responsibility of attendants for damage and accidents.

J. G.

Accidents to Steam-boilers.

(Annales des Ponts et Chaussées, 1901, p. 299.)

The annual résumé of the Official Reports relating to accidents to steam boilers in France for the year 1899.

Details are given of the date, the situation where the boiler was fixed, type of boiler and purpose for which used, circumstances of

the accident, and the consequences and presumed cause of the accident.

Twenty-six accidents occurred to boilers heated partially or entirely on the exterior, of which fourteen were water-tube boilers; and twenty-four accidents occurred to internally heated boilers.

A further Table gives the presumed cause of the accident, this being due in thirteen cases to defective conditions of manufacture or fixing, in twenty-six cases to ill-usage, in nineteen cases to defective maintenance, and in five cases no definite cause could be ascertained. Sixty-three causes are thus given for fifty accidents, as in thirteen cases two causes have contributed to the result.

Two Plates with fifty-six figures illustrate the details of these accidents.

H. I. J.

Steam-Meter.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen- Betriebes, 1901, p. 717.)

The flow of steam from one vessel into another is governed by certain laws which were experimentally established by Zeuner and Navier. The formula embodying these laws is:—

$$G = y\,F\sqrt{\frac{(P-p)\,p}{P\,v}}$$

where G is the weight of steam issuing per second, v the volume in cubic metres per kilogram, F the area of the outlet in square metres, P the maximum absolute steam pressure, p the pressure of the medium surrounding the outlet, and y a constant depending on the form of outlet.

Recently an apparatus has been constructed by which this formula is automatically worked out and the result recorded on a rotating drum. The instrument is fixed on the steam-pipes in such a way that the position of one point on a rod indicates the difference of pressure driving the steam forward, and the position of a point on another rod indicates the maximum pressure. These rods are attached to springs and are parallel to one another; the forces exerted by the springs are in the directions of the lengths of the rods.

To each of these two rods is affixed, by its edge, a disk, the outer edge of which is a curve of a particular form, different for the two rods. The disks are in the same plane, and their curved edges face one another.

A lever is now arranged in such a manner that its fulcrum and [illegible] end are constrained to remain on the outer edges of the two [illegible], while they can move along these edges. The other end of

the lever holds the recording pen, which leaves its trace on a sheet of paper moving round on a drum driven by clockwork in the usual manner.

This instrument will measure the quantity of steam flowing steadily out of one vessel into another to within 1 per cent.

J. G.

Experiments on a Single-Cylinder Condensing 500-*HP. Steam-Engine.*

(Revue de Mécanique, 1901, pp. 133 *et seq.*)

These experiments were carried out at Paris by the late Mr. Hirsch, on a steam-jacketed condensing-engine made by Messrs. Weyher and Richemond. They had for their object to test the engine under practical working conditions, while varying successively the speed, power developed on the brake, pressure of the steam and degree of vacuum, other points being kept constant, and to determine the effect of these changes separately on the consumption of steam per B.HP.-hour. The quantity of steam used was measured in two surface condensers. The diameter of the cylinder was 25·6 inches, stroke 4 feet 3 inches. The steam distribution was effected by four flat revolving valves, driven in a somewhat similar way to Corliss valves, and specially designed with the object of making the clearance spaces as small as possible, viz., 1·11 per cent. of the total volume described by the piston. The two valves for admitting the steam were acted on by the governor. The barrel and covers of the cylinder were jacketed with steam from the boiler. The amount of priming water was determined by a novel method, namely, by colouring the feed-water and comparing it with the colour of the water drawn from the condenser. The two tubes containing the two liquids were lit by an optical arrangement casting a strong light through them, by means of which an observer could easily detect the smallest differences of tint. The depth of water seen through was 5 feet. The amount of priming water in the steam thus ascertained was so minute that it could be taken as a negligible quantity.

The basis of all the experiments was the B.HP. determined by the load on a brake. Indicator diagrams were also frequently and carefully taken, but these were not considered so reliable as the brake load. Trials were made at four speeds of 60, 70, 80, and 90 revolutions per minute, and at each of these speeds the load on the brake, the pressure of steam at admission and at exhaust, and the degree of vacuum were successively varied, one at a time. Thus in one set, the pressure of the steam was maintained uniform at 7 atmospheres, the speed at 70 revolutions per minute, and the B.HP. at 200, while the vacuum was varied from 25½ inches to zero. In two consecutive series at 200 B.HP. and 250 B.HP., only the

pressure of the steam was varied from 3·73 atmospheres to 8·11 atmospheres, all other conditions remaining the same. Other trials showed the effect on the consumption of steam of varying only the load from 188 B.HP. to 452 B.HP., and the speed from 60 revolutions to 90 revolutions per minute, the pressure and vacuum being uniform. The consumption of steam per B.HP.-hour under all these varying conditions is plotted in a number of curves, which, together with numerous drawings of the engine and the apparatus used, are given in the original Papers. Taking all the trials, the greatest economy was obtained with a consumption of steam of 15 lbs. per B.HP.-hour, at a speed of 60 revolutions per minute, and 198 B.HP. The mechanical efficiency varied from 83 per cent. to 98 per cent.

B. D.

Superheated Steam for Turbines. E. Lewicki.

(Zeitschrift des Vereines deutscher Ingenieure, 1901, p. 1716.)

While for reciprocating engines the degree of superheat is limited to 350° C. or 380° C. on account of lubrication, with steam-turbines the same difficulties do not present themselves, and the Author himself used steam at 500° C. in experiments to determine the comparative merits of saturated and superheated steam for the de Laval turbine.

With saturated steam at 164° C. the brake HP. was 44 and the steam used 17·7 kilograms (39 lbs.) per B.HP. per hour. By superheating to a temperature of 500° C. the power given out rose to 51·9 HP. and the amount of steam used fell to 11·5 kilograms (25·35 lbs.) per B.HP. per hour. The heating values of the steam used in the two cases were 11,610 calories (46,043 B.T.U.) and 9,390 calories (37,240 B.T.U.) per brake HP. per hour in each case. One reason for this increase in efficiency is the diminished resistance of the turbine-wheel when revolving in superheated steam. That this lessening of the resistance actually occurs was proved by driving the turbine-wheel from a calibrated electric-motor, the wheel-chamber being filled with air, then with saturated steam, also with steam superheated to different temperatures. Details of these experiments are contained in the Paper.

Another source of the increased work done by the superheated steam is its greater steam energy per lb. weight of the steam, this varying as the square of the velocity. With an increased velocity of the jets of steam the hydraulic efficiency of the wheel must diminish unless the rate of revolution of the wheel is greatly increased; but against this again the temperature of the exhaust-steam must rise under the same conditions, and that this is in fact the case was shown by experiments also detailed in the Paper.

From his investigations the Author concludes that, with a high degree of superheat and a correspondingly high steam-pressure,

the diminution of hydraulic efficiency is more than counterbalanced by the increase in mechanical efficiency.

The quantities of steam given above were measured by means of a piece of apparatus used as a surface condenser, and the measurements fully confirmed the theoretical formulas for the flow of steam through orifices.

J. G.

The de Laval Steam-Turbine. A. Schmidt.

(Zeitschrift des Vereines deutscher Ingenieure, 1901, p. 1678.)

When, as in the case described by the Author, additional power is required in a factory and room is very limited, this question of space alone brings the steam-turbine as prime mover into consideration. Besides occupying only a small space both horizontally and vertically, being of comparatively small weight, easy of erection and requiring no heavy foundations, the de Laval turbine has the further advantage, when compared with the reciprocating engine, of simplicity of construction and consequent freedom from the necessity for such constant and skilled attention as the ordinary steam-engine requires.

The de Laval turbine can be easily governed to run at a constant speed under varying load, and it can have the full load removed at once without any danger of racing. For driving an electric-lighting plant the Author contends, on the basis of comparative tachographic readings, that so far as steadiness of the light is concerned the de Laval steam-turbine is superior to the reciprocating engine.

In the present instance the firm who contracted to supply two steam-turbines of 100 HP. each, guaranteed that the steam consumption would not exceed 9·1 kilograms (20 lbs.) per brake HP. per hour, the steam being saturated at 11 atmospheres (156·4 lbs. per square inch) with 64 centimetres (25·2 inches) vacuum. If the steam for the condenser-pump is included the figure becomes 10·2 kilograms (22·5 lbs.) of steam per HP. per hour.

After having been erected and running for about 6 months the turbines were subjected to a lengthened test. The boiler pressure was 12·4 atmospheres (176·3 lbs. per square inch), and after leaving the boiler the steam passed through a superheater, whereby it attained a temperature of 283° C., this becoming reduced at the throttle-valve to about 208° C.; the absolute pressure in the condenser was 0·16 atmosphere (2·27 lbs. per square inch). It was found that the two turbines were together performing work at the rate of 240 HP., and the steam used, including that for the 10-HP. condenser turbo-pump, amounted to 8·16 kilograms (18·1 lbs.) per brake HP. per hour.

The Author also gives the results which had been communicated

to him, of the brake test of a 100-HP. de Laval steam-turbine. In this case the steam temperature behind the throttle-valve was 260° C., the vacuum in the condenser 65·5 centimetres (25·8 inches), and the consumption of steam, including that for condenser-pump, was 6·98 kilograms (15·4 lbs.) per brake HP. per hour.

J. G.

Design of Gas-Engines. RUDOLPH BARKOW.

(Zeitschrift des Vereines deutscher Ingenieure, 1901, p. 1640.)

The data for the design of a gas-engine have reference to (*a*) the chemical and physical properties of the gas—its calorific value, the degree of richness or poverty, and its explosibility at different pressures, (*b*) the power required of the engine, and the rate of revolution. It is assumed that the expansion and compression are adiabatic, with the same values in each case for k the index of v the volume. The rounding off of the corners of the diagram is allowed for by introducing a coefficient η_i. The degree of expansion is the ratio which the volume included between the piston and the back end of the cylinder at the commencement of exhaust, v_e, bears to the corresponding volume at the point of explosion, v_c, and is denoted by ϵ. On the basis of adiabatic expansion, and with the notation as indicated, the Author obtains the following expression for the mean effective pressure:—

$$p'_m = \eta_i \frac{1}{k-1}\left(1 - \left[\frac{1}{\epsilon}\right]^{k-1}\right)\frac{1}{\epsilon - 1}(p_e - p_o\, \epsilon^k) \quad . \ (1)$$

p_e is the pressure of explosion and p_o the pressure at the commencement of the exhaust stroke.

The next point is the calculation of the pressure of explosion, and to determine this the following equation is made use of:—

$$d\,Q = A\left(\frac{d\,(p\,v)}{k-1} + p\,d\,v\right)$$

where A is the heat equivalent of work. The Author introduces a coefficient of quality of explosion η_e, which is to enable him to express the extent to which the whole of the heat of the gas Q is actually made available in producing pressure. Putting p_o for the pressure at commencement of compression, and v_c as before indicating the cubic space behind the piston at the end of compression, the integration of the expression for Q derived from the above formula leads to the following value for the pressure of explosion—

$$p = \eta_e \frac{k-1}{A}\frac{Q}{V} + p_o\,\epsilon^k$$

Introducing this value of p_e into equation (1), denoting by K the value of the term

$$\frac{1}{A}\eta_e\left(1-\left[\frac{1}{\epsilon}\right]^{k-1}\right)$$

and using H for the calorific value of the gas per cubic metre, also calling p''_m the back pressure, the expression for the mean effective pressure reduces to

$$p_m = \eta_i K \frac{H}{1+a} - p''_m$$

a being the proportion of air to gas in the explosive mixture.

As to the values of the constants, A is equal to $\frac{1}{424}$, η_e varies from 0·4 to 0·6, η_i from 0·6 to 0·8; the value of k for ordinary gas is 1·40, and somewhat less for poorer gas, say 1·35.

Having obtained the mean piston pressure by means of the above expression, the size of the cylinder can be fixed and the details of design proceeded with.

J. G.

A New Oil-Gas Generator.

(The Engineer, 20 December, 1901, p. 625.)

The Moorwood-Bennett carburetter is intended for use in conjunction with ordinary gas- or oil-engines, so as to allow of the employment of oils of high flash-point. It consists of three concentric cylindrical vessels; in the outside vessel are two openings, one connected to the exhaust from the engine and the other to the atmosphere. Through the centre one air is drawn in at the top, its quantity being regulated by a disk at the bottom connected to a vertical spindle fitted with a screw and hand-wheel. The intermediate vessel is connected to an oil-reservoir, consequently the air drawn through the central tube passes down through the oil in it and up through the oil in the intermediate vessel, and thence through perforations to the supply-pipe to the engine. The exhaust gases in the outer cylinder all the time heat the oil, with the result that the air drawn through it becomes charged with oil vapour and may be used in any type of gas-engine as an explosive charge. Practically all the by-products of the oil are prevented from entering the cylinder and may be drawn off from the carburetter.

A. W B.

On High-Pressure Fans and Centrifugal Pumps.[1] A. Rateau.

(Bulletin de la Société de l'Industrie Minérale, 1902, p. 73.)

This is a long memoir describing several new developments of the Author's well-known centrifugal fan in the direction of air compressing and high lift pumping, when driven at a high speed by rotatory motors, electric motors, or steam turbines. The first of these is a high pressure fan of 10 inches diameter driven directly by a steam turbine of 12 inches, which has been tried at the works of the constructors, Messrs. Sautter, Harlé & Co., Paris, at different speeds varying from 1,000 to 20,200 revolutions per minute, the maximum air pressure realised being more than half an atmosphere (5·8 metres water gauge, 17 inches of mercury) with a discharge of 0·76 cubic metres per second (2,460 cubic feet per minute). The peripheral speed at the highest number of revolutions is 265 metres (870 feet) per second. The combined efficiency of the turbine and fan varied between 26·7 and 30·7 per cent., made up of 50 per cent. for the former and 56 per cent. for the latter element. The useful effect with a discharge of 0·7 cubic metre per second is 45 HP. for 80 brake HP. in the turbine shaft. This class of fan is suitable for blowing purposes in foundries or for blast furnaces where not more than 7 lbs. or 8 lbs. pressure is required. It will, however, be possible to compress up to a much greater degree by coupling several similar fans in tension; for instance, 5 atmospheres might be realised by a combination of four fans. For a blast furnace making 160 tons of pig-iron per day and requiring 19,000 cubic feet at half an atmosphere pressure a 32-inch fan, driven by a steam turbine of the same size at 6,000 revolutions per minute, would be required, and as this represents about 500 effective HP. a yield of 40 per cent. might be anticipated, or a consumption of not more than 19·8 lbs. of steam per useful HP. hour. Numerous applications of the same system have been made for pumping water, the fan being driven by an electro motor, but in these cases about 30 metres lift is the maximum that can be attained under good conditions of yield with a single fan wheel, and for greater heights the multicellular form, in which several similar pumps are mounted on the same shaft, is used. In this case very considerable pressures may be attained. The largest number used hitherto is seven pumps of 270 millimetres diameter on one shaft, and with this, lifts of 90 metres to 144 metres have been obtained, with a combined efficiency of 58 per cent. Somewhat similar results were obtained with a five-cell combination driven by a continuous-current motor with a vertical shaft and arranged for use as a shaft-sinking pump. With direct driving by a steam turbine, however,

[1] A fully illustrated translation of this Paper appeared in *The Engineer*, March 7, 1902.

very remarkable results have been realised with a small single pump of 80 millimetres (3·17 inches) diameter, which at different speeds, varying between 9,000 and 18,000 revolutions, lifted from 7 to 8 litres per second to a maximum height of 304 metres. With 12 litres per second raised 263 metres (128 gallons raised 864 feet), a useful effect is obtained of about 42 HP. for 134 HP. expended. The Paper concludes with a design for a steam-driven centrifugal pump suitable for town water supply, giving about 500 HP. at 1,800 revolutions, which only covers a space measuring 14 feet by 4 feet 2 inches.

H. B.

A Pulsating Air-and-Gas Compressor. F. BRUYÈRE.

(Revue Universelle des Mines, vol. lv., August, 1901, p. 125.)

This is an arrangement invented by Mr. E. Gobbe, of Jumet, Belgium, for compressing gases by the direct impact of a mixture of gas and air exploded in a closed chamber, upon air or gas at ordinary pressure enclosed in an adjacent chamber, which is compressed by the momentary increase of volume of the burnt gas until it becomes sufficiently dense to open a discharge-valve and escape to the compressor reservoir or blast main. In the arrangement figured the explosion-chamber is a vertical cylinder with a chimney at the top having a stop-valve which, under ordinary conditions, is kept open. At the bottom there are two long horizontal tubes connecting with the air- and gas-supplies respectively. The latter terminates in a funnel-shaped pipe pierced with numerous apertures intended to facilitate the mixture of gas which arrives from opposite ends. Each supply is provided with a regulating admission-valve, a suction-valve opening inwards, and a discharge-valve opening outwards placed at some distance from the explosion-vessel. To start the apparatus the explosion-vessel is first raised by burning gas in it to establish the chimney draught when the gas-supply is cut off for a moment to extinguish the flame. It is then re-opened and the chamber fills with gas and air to the explosive point, when it is ignited either by flame or electrically. The force of the explosion closes the chimney-valve and those on the intakes of either supply, and the mass of heated gas flowing backwards acts like a piston on the air and gas enclosed, compressing and forcing them through the discharge-valves to the reservoir. With the fall of pressure on cooling the chimney-valve re-opens and those on the discharge sides close, and the burnt gas escapes to the air. Fresh gas and air then arrives and the operation is renewed. An experimental apparatus of this kind was tried for some months in connection with a blast furnace at Montceau, but the trials came to an end owing to the blowing out of the furnace. Although very roughly constructed it was so far successful as to work automatically at 12 to 14 explosions per minute, and gave

air compressed to between 10 to 14 inches of mercury, but owing to the want of measuring arrangements the yield could not be determined. On the basis of calculation the Author considers that the air necessary for the production of a unit of pig-iron may be compressed by the consumption of half its volume of blast-furnace gas without requiring a blowing-engine, boilers, or other mechanical applicances.

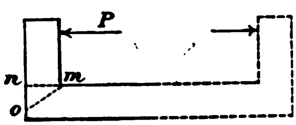
H. B.

Strength of Curved and Angular Parts of Machines.

C. BACH.

(Zeitschrift des Vereines deutscher Ingenieure, 1901, p. 1567.)

The Author's attention was particularly drawn to this question by the fracture of the bearing of a steam-engine crank-shaft right across from near the underside of the shaft to the outside. The cap was also broken.



The general case is represented in the figure. It is evident that it is more reasonable to expect a fracture through a line $m\,o$ than through $m\,n$. Calling the angle $n\,m\,o = a$ and $n\,o = 2\,c$, and applying the usual theory of bending, the following equation determines the limit of the force P

$$\beta_o \frac{P \sin a}{f} + \frac{P\,(a + c)}{\theta}\,e \lesseqgtr k_b.$$

In this formula e is the distance of the extreme fibre, k_b is the safe bending stress, f is the area of the section through $m\,o$, β_o is the ratio of the safe stress in bending to the safe tensile stress. θ is the moment of inertia of the section through $m\,o$. The angle a is to be such that the total stress is a maximum.

The estimation of the strength of such parts on the basis of this formula has always been, in the Author's opinion, unsatisfactory, and moreover the formula gives an over-estimate of the strength and an under-estimate of the actual maximum stress endured.

The Author tested two hollow castings shaped as in the figure by fracturing them with forces applied as indicated.

The fractures followed lines $m\,o$, making an angle of about 45° with $m\,n$.

The stress at fracture, calculated according to the above formula, averaged 735 kilograms per square centimetre (4·66 tons per square inch), while the bending strength of the material calculated from the fracture of straight pieces cut from the broken castings averaged 2,404 kilograms per square centimetre (12·72 tons per square inch).

It is thus seen that the calculation of the strength of such bent or sharply curved parts by the ordinary formula gives a stress which is about one-third of the actual stress, and that, if such a formula is used, one-third of the stress there must only be allowed which is considered to be safe in a straight bar.

J. G.

Connection of Surface and Underground Surveys in Missouri.

W. E. Gordon.

(Mines and Minerals, 1901, p. 559.)

In the lead and zinc ore region of south-west Missouri, very complicated problems are frequently presented to the mine surveyor. Owing to the small size of the concessions, and the limited capital of the lessees and the desire for a large output when the price of ore is high, mining is carried on in a somewhat unsystematic manner. When abandoned workings are drained by the pumping of lower levels, the surveyor is often called upon to survey the abandoned workings in order that they may be reached from other shafts. The Author describes the manner in which he makes the connection of surface and underground surveys through shafts more or less out of repair and through a shaft that had been bent into a curved form. The plumb-lines were tied together with the aid of a cross-piece so as to hang as far apart as possible and yet be clear of the sides of the shaft. At the top they were led outwardly to posts set in firm ground. At the bottom of the shaft they were connected by another cross-piece, and lower down in the drift they were separated by a stretcher bar of light pine from the ends of which the plumb-lines are continued down and terminate in two heavy plumb-bobs of equal weight. In this way an extended base is obtained at the surface, the contracted conditions in the shaft are dealt with, and an extended base line of convenient length is obtained when the drift is reached.

B. H. B.

The New Adit at the Raibl Mines in Carinthia. S. Rieger.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen Vereins Mittheilungen, 1901, p. 95.)

For the drainage of the deeper workings of the Raibl Mines in the Carinthian Alps a new adit has been commenced at Mittelpreth, 650 metres above the sea-level, which is intended to strike the mines 56 metres below the bottom of the deepest shaft at a distance of 4,940 metres. The cross section is 12½ metres

broad and 3 metres high, giving room for a double line of 24-inch gauge mine railway. The rock is dolomitic limestone, but as the work has been done entirely from one heading it will require about six years for completion. The local mining authorities were in favour of using rotary hydraulic boring machines, utilizing a high fall obtainable from the Predilka stream; but the Ministry of Agriculture, under whose auspices the work has been undertaken, decided in favour of electric boring machines, mainly on the ground of the possibility of testing the method more completely than could be done by private owners, with the further advantage of stimulating improvements, so that another source of power is obtained by storing water in the hollow of a concrete dam, which is led to the power-house by a 14-inch steel tube 300 metres long. The generator is a Siemens alternator driven by a Voith suction turbine of 45 effective HP., producing current of 5,000 volts, which is carried by bare copper wires to a transformer near the tunnel mouth, where it is reduced to 500 volts, and partly applied for working two ventilators and an electric locomotive, and partly carried forward in the tunnel for lighting and working the boring machines, for which purpose it is converted to continuous current by a transformer placed near the fore-breast. The ventilators of 5 HP. each displace 30 cubic metres of air per minute at 280 millimetres water-gauge in the working face, distant 940 metres, in September 1901. The electric locomotive of 5 HP. hauls three to four wagons, carrying 10 cwt. each at a time. The boring is done by two machines (construction not stated), which drill eight holes each, from 1 to 1½ metre deep, in 4 to 5 hours. Fixing and removing the machines require about 30 minutes each, blasting about an hour, which leaves from 1 to 1½ hour of the 8-hour shift for clearing out the broken stuff and dressing down the roof by one or two hand-bored shots. At first the progress with the machines was not very satisfactory, but in July, 1901, eighty-one sets of shots were fired, using 1,291 kilograms of dynamite, realising a length of 83 metres in driving, or rather more than 1 metre per shift. According to the surface exposures a length of 3,500 metres has to be driven in dolomitic limestone to reach the Raibler formation, and a further 800 metres to the ore-bearing limestones of Raibl, which are 640 metres broad, so that discoveries of new ore bodies are confidently expected. In addition to draining, the new adit will be of notable service for the ventilation, as well as a means of transport for the miners, who live in considerable numbers in the villages near the level mouth, and reach their work by mountain paths (Raibl being 900 metres above the sea-level), which in winter time are often dangerous from the prevalence of snow blocks and avalanches.

H. B.

On a Shaft-Sinking at Renaix, Belgium. A. HABETS.

(Revue Universelle des Mines, vol. lvi., October, 1901, p. 59.)

At the Renaix collieries in Belgium, where a single pit of 4·2 metres diameter served for winding and upcast, it was determined to sink a second ventilating shaft of 3·25 metres diameter at a distance of 19·5 metres from the first. The coal measures at this place are covered by 83 metres of newer strata, of which the lower 53 metres are heavily water-bearing. In the original sinking this ground was traversed by boring on the Kind-Chaudron method, but in the new one the ordinary method of excavation by hand was used, the bottom being kept dry by directing the flow of water downwards into the old shaft. For this purpose a heading was driven at 121 metres depth from the old pit to a short distance beyond the axis of the new one, and in this, near the middle, a dam in masonry was fixed, while at the other end a pair of steam-pumps, each capable of forcing to the surface 60 tons of water per hour was placed. When the top of the water-bearing strata was reached, a boring 16 inches in diameter at the top, reduced to 12 inches at the bottom and completely lined throughout, was put down in the axis of the pit to the level below. The water in the sinking was then drained off and collected in the lodgement behind the dam, whence it was lifted continuously by the pump in the old shaft, and the sinking went on without special difficulty at an average rate of 60 centimetres a day from 35 to 93 metres between July 1 and October 22, 1899, when a hard bed of sandstone was reached, giving a firm base for the cast-iron tubbing which was fixed between October 23 and December 2. The flow of water, which was fifteen tons per hour, subsequently increased to a maximum of 50 tons, so that it was never necessary to have both the pumping-engines at work together. Only a few short and unimportant stoppages, due to the choking of the pump-valves with sand, took place, and these might have been avoided if the settling basin behind the dam had been of large capacity.

The total cost of sinking through the water-bearing ground was 106,600 francs (£4,264), out of which there is chargeable to the special method adopted, namely, to the boring, dam, engine-room, steam-pumps and cost of pumping, about 38,000 francs (£1,520), the remainder representing the cost of sinking and tubbing. The average cost per metre was 1,600 francs (£64), as against 2,500 francs (£100) by the Kind-Chaudron process in the old shaft, which, however, was sunk at a period when materials were considerably cheaper than was the case in 1899.

H. B.

Draining a Shaft by a Bore-Hole during Sinking.

V. KADAINKA.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, xlix., October, 1901, p. 561.)

At Libuschin, near Kladno, the site of a new sinking 500 metres deep was determined by a boring 6 inches in diameter, the bottom of which was subsequently found by driving from existing workings at a distance of 2,285 metres. The rocks to be sunk through are principally sandstone and conglomerates separated by beds of shale, some of them yielding large quantities of water, the inflow in the sump ranging from 200 to 300 gallons per minute. This, under ordinary conditions, would require the use of special sinking pumps, but as the bore-hole was intact and tubed throughout, it was decided to utilize it as a means of drainage. The arrangement at first adopted was a siphon of 3-inch pipe, with arms of 11 metres and 7 metres length respectively, which was slung by a chain from a windlass 40 metres or 50 metres above the bottom, and lifted about half that height during blasting operations. The longer limb is closed by a stop-valve manipulated by a rod from above, and the shorter arm ends in a wind-bore and suction-clacks. The siphon is primed by a funnel at the top of the shorter limb, supplied with water from a pipe at the surface, which is left open until the air is completely expelled through a cock at the summit of the bend, the stop-valve at the bottom of the long arm being closed. When this is opened and the air passage closed, the siphon works on, until the next series of holes are ready for firing. A point of principal importance is the protection of the casing tube from damage by blasting, for which purpose a safety-tube is inserted when the siphon is not at work. This is a 4-inch Mannesman steel tube $\frac{1}{8}$ inch thick, 7 inches long, supported by a flanged cover on the top of the casing tube with a shorter length of a smaller tube forming a stopper. The length is so chosen as to extend some distance below the bottom of the shot holes. This gives sufficient protection against all but slight indents in the outer tube; but on one occasion, when the night foreman omitted to use the safety-tube, the outer casing was badly crushed, although not sufficiently to prevent the passage of water. In the arrangement first adopted, the water collected in the shaft was led into the bore-hole casing by a hose connection; but as this was found to be inconvenient to the sinkers, it was allowed to fall into the sump to be lifted by the siphon. This made it necessary to close the top of the casing tube by a flanged cover on the long tube of the siphon, when it was found that whenever the latter was lifted lumps of ice were found on the under side of the cover, although the temperature of the air and wa er in the shaft was never below 57° to 60° F. This was due to the circumstance that the discharge of the siphon being

insufficient to fill the bore-hole, the latter acted as a very energetic trompe, having a fall of several hundred feet, and the cover not being air-tight the damp air from the shaft was drawn in, and, being subjected to the high vacuum, froze in the same way as the exhaust from a compressed-air engine. This has led to a great simplification, the heavy siphon with its valves having been replaced by a plain one, whose longer limb is formed by the inner safety-tube, and the shorter one by a U bend connected with the short stopper tube and a length of armoured hose-pipe dipping into the sump. When this is placed in position, with the covering flange pieces luted with clay, an inch hole is bored through the casing pipe at the level of the water in the sump, allowing the rising water to flow into the bore-hole. This starts the vacuum, exhausts the siphon, and sets it to work without any special handling when the hole in the outer tube is stopped with a wooden plug. When the holes are ready for blasting the hose and U bend are removed, the short stopper is inserted, and two or three of the holes in the outer tube are opened to allow some water to flow into the bore-holes. When the shots are fired, usually sixteen to eighteen at a time, a workman removes the stopper, replaces the U tube and hose, and the siphon goes to work at once. The arrangement so far has proved a complete success, the sinking going on with great regularity at the rate of 30 metres to 40 metres per month, the total depth obtained in the first six months of 1901 being 240·5 metres. The diameter is 5·7 metres (18¾ feet).

H. B.

The New Blast-Furnaces at Eisenerz in Styria.

C. Breska.

(Stahl und Eisen, 1901, p. 1346.)

This plant, which will include two blast-furnaces, each making 400 to 500 tons per day, has been under construction for about two years, the first furnace having gone into blast on November 19, 1901. The ore from the adjacent mines of the Erzberg is loaded at the calcining kilns into self-tipping buckets of semi-circular section, which pass directly to the charging hoist of the furnace without reloading, the communication being by a tunnel 1,200 metres long with a railway worked by electric locomotives. As the mines are worked continuously, with the exception of Sundays and holidays, no great storage is required, only 100 4-ton loaded wagons being kept in reserve. It is, however, different with the coke, which is brought from Westphalia and subject to delays in transit during the winter season from snow and other causes. It is therefore necessary to keep a large supply on hand, and for this purpose a storage-shed 590 feet long has been provided with a central high-

level bunker holding 16,000 tons, or about four weeks' supply. For ordinary use two lines of hopper-shaped bunkers are provided, into which the coke is discharged by hand from the railway wagons, the outlet being by a travelling belt feeding the charging buckets, which are of the same size as those bringing the ore, but of a different colour. Their capacity is 1·5 ton. The charging apparatus is a fixed inclined cantilever crane. The buckets arriving at the ground-level are hoisted by an electric traveller to the furnace-top, where they discharge automatically into a Brown double bell and hopper charger. Each bucket of ore receives a proportion of limestone, so that ore and flux are charged together. The furnaces are 30 metres (98·4 feet) high, each one having sixteen 6-inch tuyeres, four down-comers, with two dust-cleaners and four Cowper stoves of the same height. The whole of the slag is granulated. It is not possible to use a casting machine, as the metal being highly manganiferous spirts in cooling, so the casting is done in chills in the ordinary way, but the pigs are to be lifted by electro-magnets, which will deliver them into buckets similar to those used for ore and coke for delivery by a cantilever crane to the railway wagons. At present there are three Riedler blowing engines, each delivering 35,000 cubic feet of air per minute at 15 lbs. pressure, but when the second furnace is ready two more will be added. These will be driven by gas-engines.

H. B.

Electric Pumping-Machinery for Mines.

Dr. F. Heerwagen.

(Zeitschrift des Vereines deutscher Ingenieure, 1901, p. 1549.)

The Horcajo silver- and lead-mine in the province of Ciudad Real in Spain, owned by a French company, to which the Author of this Paper acts as engineer, has passed through several critical times owing to the difficulty in dealing with the great quantities of water. The depth of the pit is increased at frequent intervals; and, while the volume of water increases with the depth, it is, besides, important that there should be no delay in opening up lower working-levels, and no time lost in lowering the point of attack for the pumps. Direct-acting pumps, subterranean steam-pumps, and hydraulic pumping-machinery were all tried. There was trouble with the various plants through rods breaking, pipes bursting, etc. The directors finally decided to have an entirely new installation, and asked for tenders for direct-acting pumps. The time required by the contractors was, however, so long as to make it doubtful whether the working of the mine would not require to be stopped. Meanwhile the firm of Sulzer Brothers, of Winterthur, offered to adapt the then existing steam-engines above ground for the production of electric energy, and to utilize this

energy for pumping the water out of the mine by means of the new Sulzer high-pressure centrifugal-pumps direct-coupled to three-phase motors. The contract time for this scheme was so much shorter than for the first, the initial cost and estimated costs of running and upkeep were so low, and the system appearing to possess great flexibility, it was decided to adopt it, and it has now been carried out. The contract required that the pumps should start pumping from the nineteenth level, 390 metres (1,280 feet) deep, where a flow of water was anticipated of 5,900 cubic metres (208,000 cubic feet) per day, and also be powerful enough to pump later 6,900 cubic metres (244,000 cubic feet) per day from a depth of 500 metres (1,640 feet). The water is not pumped the whole height in one lift; but the pumps, with their motors, being placed in chambers off the shaft at vertical distances apart of about 450 feet, each pump has only to deal with the pressure due to a column of water of that height. The pumps have each four wheels fixed on one nickel steel shaft, and arranged two and two on each side of a pair of disks fixed in the pump casing. The water advances from the circumference of one wheel to the centre of the next through channels cast in the pump case. One of the pumps tested at Sulzer Brothers' works had an efficiency of 76 per cent. The vanes of the wheels and the guide-blades have suffered little from wear, although the water is very dirty. The motors mounted on the same base plate as the pumps, to which they are connected by an elastic coupling, are 6-pole 3-phase motors, and run about 900 revolutions per minute. According to the makers, at a tension of 1,000 volts and an output of 250 HP., the efficiency is 94 per cent. and the power-factor $\cos \phi = 0{\cdot}85$. The armature is short-circuited and the starting is effected by an autotransformer, the current required at starting being 200 amperes. The electrical and mechanical relations of the motors, and the method of running the pumps up to their full load is explained in detail by the Author.

The generators, cables, switch-boards, and the erection of the plant, particularly the manipulation of the motors and pumps in the shafts, are all described in the Paper, and illustrated by photographs and drawings.

J. G.

Thermal Emissivity in High-Pressure Gases.

(Engineering, 3 January, 1902, p. 1.)

There are hardly any experimental data on the rate of cooling of the products of explosion in gas-engines, although it has long been recognized that gases must be much better conductors or dissipators of heat under high than under ordinary pressures. The present article deals with the fourth part of a Paper by Mr.

Petavel on his experiments and researches on "The Heat dissipated by a Platinum Surface at High Temperatures." The first three parts of the Paper are only very briefly dealt with in this article. The fourth part is on "The Thermal Emissivity in High-Pressure Gases." A drawing is given of the apparatus made use of. It consists of a gun-metal or glass tube containing the gas to be experimented on, with a platinum-wire stretched along its centre and capable of being heated by passing an electric current through it. The length of wire between the potentio-meter contacts was 3¾ inches and diameter 0·045 inch, the radiating surface being ½ square inch. The small tube containing the wire was placed inside a thicker steel tube which had a water-jacket round it. The gas to be tested was admitted to the inner tube and the wire was heated; the amount of heat lost by the wire or the total emissivity was measured by the resistance to the current. The component parts of the total heat emission, viz., conduction, convection, and radiation cannot, so far, be separated. The experiments were conducted with gas-pressures up to 169 atmospheres. The results of the experiments are given in a number of diagrams consisting of curves plotted from the observations and in several tables.

C. H. M.

The American Steel Industry.

(Engineering, 27 December, 1901, p. 873.)

The annual report of the American Iron and Steel Association shows for the first time that the United States' output of open-hearth steel has exceeded that of the United Kingdom. The total production of pig-iron in the United States for 1900 was 13,789,242 gross tons, and in the United Kingdom it was 8,908,570 tons. The total production of steel of all kinds in the United States in 1900 was 10,188,329 tons, and in 1899 it was 10,639,857 tons. In 1900, 6,684,770 tons of Bessemer steel were produced, against 1,745,004 tons only in the United Kingdom. Of the Bessemer steel in 1900, 2,383,654 tons were converted into rails in the United States. The production of Bessemer steel is declining in consequence of the preference given to open-hearth steel, of which 3,398,135 tons were produced in 1900, or 450,819 tons more than in 1899, whilst the British output for 1900 was only 3,156,050 tons. Germany is also going ahead; her production of pig-iron was 8,520,390 tons in 1900—almost equal to that of the United Kingdom; whilst in finished steel she produced 6,365,259 tons, or about one and three quarter million tons more than this country. During the year 1900, 845 mercantile steamers were built in the United Kingdom, having an aggregate tonnage of 886,627 (net) tons. During the fiscal year ending June 1900 the United States turned out 90 mercantile steamers of 196,851 gross tons, and during the year ending June

1901 they turned out 120 vessels of 262,699 tons. The advance in shipbuilding in the United States and Germany is due largely to improved methods and plant introduced into those countries. British shipbuilders are too slow in introducing improved modern methods and plant into their establishments.

C. H. M.

Iron and Steel Works in Mexico.

(Engineering, 3 January, 1902, p. 8.)

The works described are 3 miles outside Monterey and belong to the Iron and Steel Works Company of Monterey, a genuine Mexican Company with a capital of $10,000,000, who got Mr. William White, jun., of Pittsburg, to design and carry out their works for them. Monterey is the great centre of the deposits of iron ore and coals, as well as limestone; and manganese ore is also found there. The principal iron ores are, magnetite, hematite and brown hematite. The Company own extensive coal-fields. The capacity of the plant is equal to an annual output of 128,000 tons at present, consisting of steel rails, beams and shapes, billets and bars, pig-iron and castings. The mills are capable of working up the produce of four blast-furnaces. At present only one blast-furnace is at work and three open-hearth furnaces. There is no Bessemer plant, but provision is made for adding it. The equipment of the works is very complete in every respect, electric travelling-cranes being provided where required. There are gas-producers to supply gas for the open hearths, soaking pits and reheating furnaces. There is a foundry capable of turning out 30 tons per day, also a machine-shop and a forge, all fitted with modern tools. The electric-power generating-plant is in a separate building supplied with two Babcock and Wilcox boilers of 250 HP. each and two horizontal engines, each driving a 150-kilowatt generator.

The article is illustrated by a map of part of Mexico round Monterey.

C. H. M.

Electric Installations in the Mines of the Grand Duchy of Luxemburg. A. Koch.

(Revue Universelle des Mines, 3rd series, vol. lv., 1901, p. 116.)

In the iron mining region of Luxemburg there are two groups of mines in which the power required for underground operations is furnished by electro-motors. The most important of these is that of the Aachan Smelting Company of Rothe Erde, where a generating-station is placed at the smelting works. This

includes three groups of steam-driven dynamos giving continuous current of 525 to 550 volts to a total of 1,230 HP., which is utilized for haulage and hoisting, pumping, ventilating and working rock-drills. Three beds of ore are worked simultaneously, the two lower ones being connected by a shaft, 25 metres deep, which raises the produce to the level of the upper seam open workings. In these lower beds the ore is drawn by electric locomotives on lines with a rise of 1 in 33, in train-loads of 60 tons, at a speed of 3 metres per second, to the shaft, where it is lifted by an electric winding-engine of 45 HP., with a capacity of 1,500 tons per day. At the top of the shaft similar electric locomotives of 90 HP. draw it by the roads in the upper bed directly to the furnaces. Pumping is done by a combination of groups of centrifugal and plunger pumps. The former, including three Brodnitz and Seidel centrifugal pumps, each of 5 tons capacity per minute, driven directly by a dynamo, placed at the bottom of the works and lifting 17 metres to the feed-cistern of the upper group, which includes 5 plunger pumps and an Enke centrifugal, of a collective capacity of 10 tons per minute raised 35 metres. In a dip heading in wet ground beyond the general air-circulation, special ventilation is provided by an electrically-driven fan giving 155 cubic metres per minute, and the driving is done by two Siemens and Halske rotatory rock-drills worked by a current of 250 volts, which drill a 45-millimetre hole 1 metre deep in 6 to 8 minutes. With these machines, with seven men working three shifts daily, the level 3½ metres square is driven on average 70 metres per month. At the mines of Messrs. C. and J. Collart, which are worked by dip slopes of 3° to 5° inclination, the electric energy is produced by Otto gas-engines, driven by Dowson gas produced from small anthracite or coke and steam. The gas contains about 23 per cent. of carbon monoxide and 17 per cent. of hydrogen, with a calorific power of 1,100 to 1,400 calories per cubic metre. The yield is from 4 to 5 cubic metres of gas per kilogram of fuel, and the consumption per HP.-hour 0·5 kilogram to 0·6 kilogram, from 10 per cent. to 15 per cent. of which is consumed by the steam-boiler and superheater.

The total heat utilization in the engines is from 25 per cent. to 30 per cent. of that contained in the fuel, or from 2½ to 3 times that obtained with steam.

The generating plant consists of two Otto double-cylinder engines of 125 HP. each, coupled directly to Lahmeyer continuous current dynamo, with a voltage of 500 to 550. The starting of these engines is effected by a small barring engine of 2 HP. driven by compressed air.

The electricity produced by the dynamos is applied to lighting and ventilating the underground working, drawing and hauling. The most important part of the plant is that devoted to pumping, which includes two large centrifugals, each lifting 2 tons per minute 45 metres, and three smaller ones of 1 ton lifted 20 metres, to which an electric-driven duplex plunger pump-engine by Ehrhard

and Sehmer, lifting 2 tons 45 metres per minute, has lately been added. The underground haulage and extraction is done by two small electric locomotives of 24 HP. each.

H. B.

On Mineral Oil Firing for Open Hearth Furnaces in Russia. A. BYSTROM.

(Oesterreichische Zeitschrift für Berg- u. Hüttenwesen, vol. l., January, 1902, p. 34.)

In the steelworks in the neighbourhood of St. Petersburg steel melting and re-heating furnaces are fired with naphtha residues (mazut), costing 13*s.* per ton at Baku and 45*s.* at the works. In the earlier or drop system, which is similar to that originally adopted in the Willenstrom furnace, the oil is fed in drops through a series of apertures in the roof of a small heated chamber in the neck of the gas flue, where it is vaporized and fired by the heated air from the air-flue above. This arrangement is fairly suitable for heating furnaces, but with the higher temperatures required for steel-melting the wear in the combustion chamber is very considerable, and complete repairs are required after about fifty heats. The system now generally adopted is to gasify the oil in the gas regenerators, after subjecting it to a preliminary heating by steam coils to 40° or 50° C. in storage cisterns, whence it is pumped into an accumulator giving from 5 atmospheres to 7 atmospheres pressure. The feed is effected by a Körting pulverizing injector, with nozzles of varying aperture from 1½ to 3 millimetres, blowing into the side of the regenerator near the bottom. A small accessory air supply is introduced at the same time to burn the first portion of the oil-gas which would otherwise choke the brickwork by a deposit of coke. The arrangements of the regenerator are similar to those for producer gas, except that the arch of the chamber must be raised about 6 inches, as the specifically lighter oil-gas attacks the brickwork very readily. A newer and better method, which, however, has as not yet been generally applied, is to feed the furnace through concentric nozzles, the inner one carrying the oil and the outer one air at high pressure, when absolutely perfect combustion is obtained and the gas regenerators are dispensed with. In this system five water-cooled injectors are required, two for each end of the furnace, and a central one in the crown of the arch. Under ordinary working conditions, with 10 ton to 15 ton open hearth steel-melting furnaces, the consumption of oil is about 20 per cent., or in some cases 18 per cent. of the weight of the materials charged, the endurance of the furnace and the speed of working being about the same as with producer gas-firing.

H. B.

Machines for Manufacturing Peat Fuel in Sweden.

J. G. THAULOW.

(Teknisk Ugeblad, Christiania, 1901, p. 491.)

For the production of peat fuel in Sweden, large powerful portable machines have latterly been more and more employed upon the peat bogs themselves. They thoroughly mix and grind up the peat earth, and force it out through an orifice of 5 to 8 square inches area, whence it issues in the form of a long pole or column, which is cut up into pieces of suitable length. After lying 2 or 3 weeks on the ground, the pieces can be piled up together; and 2 or 3 weeks later they are dry enough to be stacked, stored, or shipped. Peat thus pressed has the advantage over ordinary turf peat as cut from the bog, as well as over kneaded peat, that it is a denser and heavier fuel, which will stand conveying to a greater distance, and more of it can be dried per acre of drying ground. It weighs from 590 to 670 lbs. per cubic yard (or say about 3½ cubic yards per ton), and costs about 5*s.* 6*d.* per ton loaded into wagons at the bog, including all charges. It sells at from 11*s.* to 16*s.* 6*d.* and upwards per ton. The manufacture can be carried on only during the three months May–July; the men work by bargain, and can earn from 4*s.* to 5*s.* per day.

The production of dry peat fuel from four machines working in Sweden is given in the following Table, with other particulars concerning them:—

Peat-Fuel Machine	Åkerman	Anrep	Munktell	Åbjørn Andersson
Engine power	18 HP.	38 HP.	20 HP.	..
Number of men	15 men	28 men	17 men	..
Tons of dry peat fuel produced per 10 hours	20 to 25	40 to 45	25 to 30	20 to 40
Cost of machine alone	£67	..	..	£40 to £140
Total cost with all adjuncts [1] . . .	£390	£830 [2]	£500 [2]	..

[1] Including engine, rails, wagons, and all other appurtenances.
[2] Including freight and erection in Sweden, and delivery of the machine in working order on the bog.

The Åkerman machine, made in Eslöf, has been the longest and most extensively used in Sweden; in its latest improved form it has given great satisfaction. It is driven by an independent portable engine.

Of the Anrep machines, of which the first built in Sweden was constructed in 1901 in Eskilstuna, over 500 have been made in Russia. The princfple is almost the same as that of the Åkerman; but the engine is here placed on the same truck as the machine itself, rendering the whole more compact, and easier to shift on the bog. The Anrep is also much stronger and more powerful; and is constructed entirely of iron, excepting only the knives, which are of cast steel and can readily cut through small pieces of wood

and roots. The greater and more concentrated weight has been objected to, for working on the soft Swedish bogs, particularly if the machine comes too near the edge of the deep trench in which the peat is dug; but all risk of sinking or capsizing is obviated by laying planks enough under the rails; and no mishap has thus far occurred. The Russian bogs, for which the Anrep machine was especially constructed, are shallower and harder than the Swedish; and there it works remarkably well.

For Swedish bogs a smaller and lighter Anrep machine has been made at the Munktell Works, and tried successfully at Stafsjø Peat Factory in Småland.

Last year (1901) the Åbjørn Andersson Works in Svedala began making peat machines with engine combined, but less compact than the Anrep, and of simpler construction, partly of wood for cheapness. They are of various sizes, and have given great satisfaction in working.

A public trial of these several machines is to be made in May, 1902, at the Stafsjø Peat Factory. At Sparkjœr, in Denmark, peat fuel is manufactured cheaper than anywhere else. But with machines from the Sparkjœr Works that have been used in Sweden the cost of production is about 1*s.* per ton dearer than with the Swedish machines; and the same has been the case with Dutch machines tried in Sweden. Hence machines for making peat fuel, however well they may work mechanically, must be adapted to the climate and other natural conditions of the locality in which they are employed.

A. B.

Manufacture of Peat Charcoal by Electricity. H. LANDMARK.

(Teknisk Ugeblad, Christiania, 1901, pp. 549–555.)

After a concise review of the preliminary stages in the preparation of peat for use as fuel—cutting and air-drying it on the bog, and then crushing, pressing, and drying it artificially—the principal methods of coaling the dried peat are described: namely those of Angell, Schøning, Ziegler, Holm and Tylvad, and Jebsen. Experiments on a small scale, continued during several years, having satisfied Mr. P. Jebsen that it could easily be managed to coal peat by means of an electric current, the Stangfjord Works in Søndfjord were erected in 1897 with this object, by himself and Mr. K. Faye. A start was made with six retorts and two dynamos, coaling air-dried peat brought in lighters direct from the bog, a distance of 14 miles. The first year's experimental working led to doubling the number of retorts and dynamos, adding a kneading machine and elevators, together with a turbine for driving them, and an overhead drying room, in which the peat is spread out on tiers of shelves, and dried by the heat radiated from the coaling

retorts. Yet later a large drying floor, heated by flues underneath, has been built from the designs of Mr. J. G. Thaulow.[1] Plans and sections, longitudinal and transverse, are given of the works thus completed; and the whole of the arrangements are described in detail, including the elaborate precautions taken for utilizing to the utmost possible the waste heat from the several processes.

The electric coaling retorts are vertical cylinders, 7½ feet high and 3¼ feet diameter, made of half-inch wrought-iron plate, and closed at top and bottom by covers screwed on air-tight. The walls are insulated by a lining of refractory tiles. The retorts are arranged in two longitudinal rows of six each. They are suspended on iron beams, with about two-thirds of their height hanging over the ground floor, and one-third projecting above the first floor, where the charging is done through the top covers; the peat charcoal is discharged by opening the bottom covers, and falls out into trucks running on rails beneath each row of retorts. The tar and water, drawn off through outlet pipes from the bottom of the retorts, run into a scrubber, where the greatest part is deposited. The steam and gases not here condensed pass on through a tubular condenser, where the rest of the tar and water are deposited, and whence the gas is led off to a special fire-place at the drying floor. The heat for coaling the peat is furnished through an arrangement of wires in each retort, which are connected with the switchboard and dynamo. A current of about 500 amperes with a tension of 40 to 45 volts maintains a temperature of 300°–350° C. or 570°–660° F. in the retorts. By opening a pet cock in the top cover, the progress of the coaling can be judged from the issuing steam. When it is completed, the electric current is cut off, and the retorts are left standing until the charcoal is cooled down sufficiently to bear discharging without risk of igniting. The charge is from 8 to 10 cwts. per retort, according to the dryness of the peat, which also determines the time occupied in the coaling, ranging from 3 to 4 hours. Originally one retort only could be coupled to each dynamo, and hence four retorts only could be worked at once. But by using wires made of a special alloy and arranging them better, both the strength and the tension of the current have been so considerably reduced that one dynamo can now work two retorts together. The peat should not contain more than 15 per cent. of moisture, otherwise the charcoal becomes porous and friable. Such a defect can be partly obviated by using a lower strength of current, thereby effecting the coaling at a lower temperature; but the process then becomes unduly prolonged, and consequently rendered dearer.

The four dynamos for coaling the peat are of 80 kilowatts each, and each is driven by its own turbine. There is also a lighting dynamo of 10 kilowatts, and a 40-HP. turbine for driving the kneading machine, ventilators, and elevators. The aggregate power employed amounts to 300 HP., which is supplied from four large

[1] Minutes of Proceedings Inst. C.E., 1901, vol. cxlvi. p. 236.

tarns through a water main 48 inches diameter at the intake and 2,720 feet (0·515 mile) long, with a fall of 161 feet.

Peat containing 10 per cent. moisture yields in the electric retorts 70 per cent. of charcoal and 3½ to 4 per cent. of tar; and from 7,000 to 7,700 cubic feet of gas per ton, against 8,800 to 10,600 cubic feet from coal. There is not enough tar to pay for recovering its by-products; it is therefore exported, and is delivered in Berlin for 11 marks per 100 kilograms (say 5*s*. 6*d*. per cwt.). From the tar-water however are recovered acetate of lime, sulphate of ammonia, and methyl-alcohol or wood-spirit.[1]

The peat charcoal made by electricity is firm and hard. The drier the peat, the harder and denser is the charcoal. Its chemical composition depends on the condition of the bog. Analysis of that made at the Stangfjord Works gave the following percentages: carbon 76·91, hydrogen 4·64, oxygen 8·15, nitrogen 1·78, sulphur 0·70, ash 3·00, moisture 4·82. Notwithstanding the quantity of gas evolved in coaling, the Author found experimentally that on thoroughly roasting the charcoal it still yielded about 8,500 cubic feet of gas per ton. Hence it burns with a long flame, and is particularly suitable for kiers and other steaming pans with long flues. At Stangfjord it is burnt in the iodine factory, where the steaming is so accelerated thereby that about 24 hours per week are saved in comparison with the previous use of the same quantity of coal. In foundries it has been used with good results in melting furnaces. Most of it goes for household use, on account of its being so clean, making scarcely any soot, and requiring so little draught. It is delivered in Bergen for 15*s*. 7*d*. per ton.

A. B.

Use of Peat-Gas at Motala Steelworks. J. G. Thaulow.

(Teknisk Ugeblad, Christiania, 1901, p. 451.)

Peat-gas has been employed as fuel at the Motala Steelworks, Sweden, for the past 30 years, originally for the puddling furnaces, and to a still greater extent subsequently for the Siemens-Martin furnaces. The peat is got chiefly from the further side of Lake Wetter, across which it is brought in sailing vessels, and unloaded direct into large store-houses, whence it is trammed to the gas-producers. The yearly consumption is from 13,000 to 16,000 cubic yards of dry kneaded peat, costing about 3*s*. per cubic yard delivered at Motala. Two large gas-producers are used, from which the gas is led to the Siemens-Martin furnaces through a condenser for ridding it of some of its moisture. Although the peat-gas, owing to the distance the peat has to be brought, is dearer than coal gas, it is used preferably in most

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[1] Minutes of Proceedings Inst. C.E., 1901, vol. cxlvi. p. 236.

Swedish steelworks, in consequence of the insignificant amount of sulphur and phosphorus it contains. In the rolling mills there is a smaller peat-gas producer for one of the plate furnaces; and thin steel plates especially scale less in rolling when the furnace is fired with peat-gas. The use of peat-gas in the Swedish steel industry contributes largely to enhance the quality of the steel, irrespective of the cost of fuel becoming thereby often higher than with coal. The choice of the fuel however is not always determined by its cheapness so much as by its influence upon the material produced.

A. B.

The Production of Mercury in Italy. L. Pelatan.

(Bulletin de la Société de l'Industrie Minérale, 1902, p. 211.)

Mercury ores have been found and worked to some extent in three different districts in Italy, namely, Vallalta, in the province of Belluno, Iano, near Volterra, in central Tuscany, and Monte Amiato, in southern Tuscany, about midway between Rome and Florence, the last-named being the only one of importance at present. The mines, which date back to Roman and even Etruscan times, seem to have been abandoned after the barbarian invasions, and remained unknown until about 60 years back, when attention was called to the district by the discovery of rich deposits of cinnabar in the bed of a torrent on the west side of Monte Amiato, but the most important mine, that of Siele, only dates from 1865.

The ore is entirely cinnabar, which is found in irregular masses impregnating limestones and schists, of eocene date (Siele and Santa Fiora), in neocomia limestone (Cornacchino), and in post-tertiary trachytic breccias (Abbadia di San Salvatore). The richest mineral, averaging from 8 to 10 per cent., was produced at Siele between 1865 and 1890, but since the latter year it has fallen to about 2 per cent. At Cornacchino the ore of the siliceous schists averages 0·4 per cent. to 0·5 per cent., and the argillaceous kind found at the contact of schists and limestone about 1 per cent. Formerly the mineral was treated by jigging and buddling to obtain a rich concentrate (from 10 to 50 per cent.), which was reduced by distillation in retorts, while the poorer small stuff was passed through kilns; but this method was attended with a loss of at least 24 per cent. of the contained mercury, as cinnabar in spite of its high density is readily floated away in a stream of water. By the present system of treatment there is no preliminary concentration, the ore being charged directly into the reducing furnaces, which are a modification of the Cermak furnace of Idria, with some improvements by Mr. Spirek, of the Siele mine. This somewhat resembles the Gerstenhofer calciner, the small ore being

charged at the top in a series of narrow V-shaped compartments which discharge upon the point of an inverted V in the stage below, and so on, though the entire height of the furnace which is heated by a wood-fire upon a grate at either end up to a maximum temperature of 400° C. to 450° C. The spent mineral falls below the level of the grate through a space penetrated by air circulating tubes, which cool it down to between 50° and 80°, the heated air passing to the fire-grate of the furnace. The cooled waste falls into large hoppers below the furnace, which when full are discharged into an inclined launder, whence a sudden flush of water carries the waste into the bed of a neighbouring torrent. The condenser is of the ordinary Cermak form, a series of serpentine pipes, partly of cast iron and partly of stoneware, which are cooled externally by water followed by several chambers for condensing mercurial soot. The flow of the gases through the condenser is maintained by a Root's blower, which entirely prevents the escape of mercurial vapour into the atmosphere. These furnaces are made of three sizes, the largest having a capacity of 24 tons daily, the second, or medium size, of 12 tons, and the smallest of 2 tons, the latter being specially used for the reduction of very rich ores instead of retorts. The larger sizes of mineral above about 1¼ inches side are hand-picked and treated in square or circular kilns, 1 metre in diameter and 5 inches to 6 inches high, with an addition of 5 per cent. of charcoal. These resemble lime-kilns, but are hermetically enclosed in an iron casing and provided with condensers of the kind previously described. The total capacity of the four principal smelting works in the district is nearly 200 tons per day, and their estimated output for 1901 about 350 tons of mercury, or an increase of about 130 tons on the product of 1900. The cost of a medium-size plant, including one 24-ton, one 12-ton, and one 2-ton furnace, one 6-ton kiln, and one furnace with three retorts and the necessary condensers is about £3,500, and the prime cost of mercury obtained from ore containing 0·5 per cent. to 1·0 per cent. does not exceed 3 francs per kilogram (1*s.* 4*d.* per lb.), the selling price at present being £9 per flask of 76 lbs. (2*s.* 4*d.* per lb.).

H. B.

On Copper Refining with Magnesium.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1901, p. 546.)

In the larger German works producing high-conductivity copper for electrical purposes, the use of magnesium as a deoxidising agent is now very general. When the bath is ready for casting, the surface is cleared by skimming the slag, and magnesium in the form of cubes or hydraulically-pressed rods previously heated is plunged below the surface. This is best done by binding the

piece of metal with copper-wire to the end of a copper-rod and stirring vigorously. Another method to prevent undue waste of magnesium is to enclose it in a thin case of sheet copper. When the magnesium is melted a very energetic action is set up; free oxygen, together with that contained in the bath as sulphur dioxide, cuprous oxide and carbon monoxide, being expelled with the formation of sulphur and carbon, which burn at the surface, and magnesia going into the slag, while the copper casts into perfectly solid ingots. This method, although satisfactory, requires carefully manipulating, more especially to prevent loss of magnesium by burning to waste at the surface. A better method is to use an alloy of equal parts of copper and magnesium made by the Hemelingen Aluminium and Magnesium Works. This is a brittle alloy, of specific gravity, 2·97 with a fibrous fracture and reddish grey colour, melting at 450° C., which dissolves in the copper bath without any loss of the more combustible constituent. For most purposes a total addition of 50 grams of alloy per 100 kilograms of copper (1 in 2,000) will be sufficient, which should be made by 20 grams at a time. A larger addition up to 1 part in 1,000 works beneficially in improving the strength and density of the copper. The same alloy may be used to improve alloys, such as gun-metal, bronze, brass, etc., for casting. Copper and copper alloys containing magnesium up to about 5 per cent. are likely to prove of value for technical purposes.

H. B.

Copper Extraction at Falun. K. Glinz.

(Berg- und Hüttenmännische Zeitung, 1902, p. 48.)

The old copper-mine at Falun produces two classes of minerals known as hard and soft pyrites respectively. The former, consisting of mixtures of quartz and copper pyrites, contains about 3½ per cent., and the latter, which is mainly composed of iron pyrites, about one per cent. of copper. The hard ore is roasted in heaps, about 10 per cent. of sulphur being driven off, while the soft pyrites is treated in the sulphuric acid works, about 30 per cent. of sulphur being utilized. The burnt residues, to the extent of about 45 tons hard and 12 tons soft per day, are mixed with salt (14 per cent. and 10 per cent. respectively) and ground in ball mills. The hard ore mixture is then subjected to a chlorinating roasting in Howell and White calciner, with a mechanical continuous-charging arrangement, treating 15 tons in 24 hours, and that of the soft ore is trebled in a double bed calciner working through 7 tons daily.

When complete chlorination, as shown by the ordinary tests, has been effected, the roasted material is transferred to wooden vats,

where the cupric chloride is dissolved out by weak sulphuric or hydrochloric acid, the latter being obtained by condensing the waste gas of the calciners, three classes of liquor, namely, acid wash or water from previous charges, and clean water, being used successively, the last going back as second liquor to a following charge. The liquor contains all the copper, bismuth, selenium, and silver, together with a portion of the gold contained in the ore, the remainder of the latter being extracted by a subsequent washing with chlorine water. The copper liquor is precipitated by scrap iron as cement copper, which, together with the associated mud and iron salts, is re-smelted and granulated for conversion into copper sulphate by means of dilute sulphuric acid and air in the ordinary way. The residual mud from the blue vitriol crystallizers containing gold, silver, selenium, and bismuth, is dried and smelted with litharge soda and sawdust to collect the precious metals in lead. The gold-bearing liquor from the chlorine extraction is reduced by adding a portion of the original copper extraction liquor containing ferrous chloride, which reduces the chloride of gold, producing gold and ferric chloride. The gold so obtained is extremely finely divided, and an addition of lead acetate and sulphuric acid is necessary to obtain a sufficiently dense precipitate. This is smelted with lead in the same way as the copper residues. The waste liquor from the copper extraction is worked up for ferrous sulphate, which by calcination gives red colour (rouge or colcothar), a substance that is used for house painting in Sweden, about 1,000 tons being made yearly.

The annual production of the works is as follows—

Copper sulphate	1,600 tons
Ferrous "	300 "
Iron oxide red paint	1,000 "
Silver	400 kilograms
Gold	100 "

H. B.

Magnalium. Diegel.

(Verhandlungen des Vereins zur Beförderung des Gewerbfleisses, 1901, p. 277.)

Magnalium is an alloy of magnesium and aluminium which has been found to possess valuable properties for industrial purposes. Hitherto little has been known as to its strength and elastic properties, and the Author supplies information both as to these and other important qualities of the alloy.

The bars tested contained from 2 per cent. to 30 per cent. of magnesium. It appears from the Author's results that, in the cast condition, the alloy containing from 3 per cent. to 4 per cent. of magnesium has the greatest strength and extensibility.

The following Table is condensed from the Paper.

Cast or Wrought.	Per cent. of Magnesium.	Modulus of elasticity in tons per square centimetre (tons per square inch.)	Yield Point. Kilograms per square millimetre (tons per square inch).	Breaking Strength. Kilograms per square millimetre (tons per square inch).	Extension on 4 inches	Contraction of Area.
					Per cent.	Per cent.
Cast . . .	3	710 (4508)	6·3 (4·0)	21·1 (13·4)	6·5	8
Cast . . .	4	716 (4546)	6·4 (4·06)	24·3 (15·4)	7·3	8
Wrought .	4	676 (4292)	4·2 (2·66)	14·5 (9·2)	17·6	35

For stamping, drawing and other similar operations, the wrought alloy with 4 per cent. magnesium is the most suitable, on account of its great extensibility. The wrought 6 per cent. magnalium has a strength of 25·5 kilograms per square millimetre (16·2 tons per square inch), but its ultimate extension is only about 13 per cent.

For working with cutting tools and for filing, magnalium containing 14 per cent. and more of magnesium is distinctly superior to aluminium, while for working in the cold state with the hammer the percentage must not exceed 14. When the alloy is heated to dull red it falls to pieces under the hammer if the percentage of magnesium exceeds 6.

The Author subjected bars of magnalium to the action of sea-water, and found them to be strongly attacked; so much that he considers it doubtful whether the alloy is to be recommended for use in the construction of ships or the machinery on board, for which otherwise it is very suitable.

W. B.

New Methods of Determining the Initial Velocity of Projectiles. A. C. M. FitzGerald.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1901, p. 269.)

Originally it was believed that the speed of a bullet was greatest at the muzzle of the gun and decreased from that point onwards. Later experiments seemed to show that the maximum velocity was not attained until some little time after the shot had left the gun, the explanation being that the powder gases continued to act beyond the muzzle.

After the old ballistic pendulum method had been abandoned, the time taken by the projectile to traverse a given distance was actually measured. The difficulty in this case is to measure a very small space of time with the required accuracy.

The Author and Dr. Radakovic have invented an apparatus by

which the time taken by the projectile to traverse distances from about 4 inches upwards can be measured.

The theoretical principle which is the foundation of this method recalls the old Clepsydra, only it is not a liquid that is measured, but the quantity of electricity which flows out of a condenser during the short time which the bullet requires to traverse a few inches. From the measured charge of the condenser at the beginning and end of the short time, its capacity and the resistance of the circuit, the time can be calculated according to a known formula of physics.

The apparatus required includes two wire screens, a battery, resistance coil, key, condenser, and a galvanometer. So far as the experiments have been carried they show that the velocity has its absolutely greatest value at the muzzle, from there it decreases until at about 2 feet 6 inches distance it reaches a minimum, it then begins to increase until at about 4 feet it attains a second maximum, which however is smaller than the muzzle velocity. This peculiar variation of the velocity is attributed to the air immediately in front of the muzzle being condensed by the outrush of the gases and thus offering greater resistance to the passage of the bullet, the bullet also spends some energy in the formation of its headwave. The action of the powder gases on the bullet continuing longer than these disturbing influences explains the increase of the speed to the second maximum.

Another method tried by the Author is the use of a ballistic pendulum. Instead, however, of using the old form of a box filled with lead or sand he uses a plate of hard steel.

The Author says that with armour plates the surface can be made so hard that the coating and the body of the bullet are both transformed into fine particles and almost the entire energy is spent in moving the pendulum. The results of the Author's experiments coincided very closely with those obtained by the method first described.

W. B.

Lemaire's Noria. A. Brüll.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 31 August, 1901, p. 212.)

The use of the Noria as a means of raising water has been practised from periods of remote antiquity, and attempts have from time to time been made to improve on this system. The present apparatus is chiefly noticeable from the very small size of the cups or buckets, each of which has a capacity of less than $\frac{1}{10}$ of a pint. The novelty in the construction consists in hinging the buckets on a bar placed beneath each one, and this cross-bar is riveted to the cheeks of the links which constitute the chain. In consequence of a catch placed under the bucket, it

is kept in an upright position so long as the chain remains vertical, but directly the chain reaches the over-wheel and becomes slightly inclined, the bucket, owing to the alteration in the centre of gravity, tilts over and delivers the water into a trough or channel situated under the wheel and slightly exceeding it in width. This trough is furnished with an aperture into which the exit-pipe is fixed. By these arrangements none of the water is spilt, and, owing to the small size of the buckets, the apparatus can be adapted to work in narrow bore-holes. Illustrations of the complete Noria, with details of the buckets, are given.

G. R. R.

The Supply of Water to Santiago de Chile. J. V. Salcedo.

(Anales de Instituto de Ingenieros de Chile, 1901, p. 211.)

The Author deals first with the history of the supply of potable water to the City of Santiago de Chile, and then proceeds to describe the works at present in use. He traces the history from 1541, at about which date the city was founded, and observes that the city doctor was the first to suggest the use of a spring at Tobalaba, about 6 miles from Santiago, as a suitable water-supply. The work was shortly afterwards taken in hand, and subsequently further sources of supply were added. The canal of Ramon was completed in 1829, but was not very satisfactory, as the cost of repairs was very high. The water was at that time supplied to ten public fountains or basins, whence water could be drawn for use, but the pipes were constantly becoming choked up. Although the water-supply was good at its origin, it became contaminated with surface water and impurities before reaching the fountains, and this was still the state of affairs in 1855, when the city had a population of 160,000 people. Private persons had to obtain a supply in barrels from the water-carriers, at a cost of 15*d.* for 30 gallons. The water was at times so muddy as to necessitate filtration, and this was effected in a rude manner by putting into the water-jar macerated shoots of the tuna bush, and clarification took place in about 10 hours.

In 1859 a project was brought forward by Mr. Vijil, an engineer educated in Europe, who desired to form a private company with the sole right of supplying water for 30 years. He obtained a concession, but was unable to find the capital, and finally he entered into an agreement by which the municipality became a party to the scheme and found most of the capital.

Water rates were based upon the rentals of the houses. The reservoirs De la Reina were completed in 1865, and in 1868 it was decided that all water should be paid for by meter, at the rate of 11·4*d.* per 1,000 gallons.

In 1872 the municipality bought the share of Mr. Vijil, and the

Author gives an account of the extensions which have subsequently been made in the construction of larger reservoirs, filter-beds, and extension of the area of distribution.

E. R. D.

A Rock-Fill Dam with a steel core across East Canyon Creek, Utah. W. R. HEADESBY.

(Engineering News, 2 January, 1902, p. 14.)

This dam has been constructed across the East Canyon Creek for the purpose of forming an irrigation reservoir, the area of which is 225·4 acres, and the capacity 167,500,000 cubic feet. It was at first built 68 feet high above the gravelly bed of the creek—the width at ground level being about 54 feet. It was subsequently raised 25 feet. The core of the dam is formed of steel plating, the bottom and side edges of which are imbedded in concrete in a groove excavated in the rock for the purpose. The steel-plating is imbedded between two walls of asphalt concrete 4 inches thick, greatly increased in thickness as they approach the rock. On each side of this core of steel plates and asphalt concrete a dry rock wall is built, the stones being carefully laid and bonded, with all the spaces filled with broken rock. Each wall is 20 feet thick at bottom and 10 feet at top. On the upstream side of the dam a face wall 5 feet in thickness is laid on a slope of 1 to 1. On the downstream side the face wall is the same thickness and laid on a slope of 2 to 1. The portion of the dam between these walls and the walls next to the core is filled with rock dumped in, with all the spaces carefully filled with stones. A wasteway is provided 30 feet wide and 6 feet 6 inches high. An oval discharge tunnel is provided, containing two 30-inch valves for regulating the discharge. The article is illustrated by a number of drawings.

C. H. M.

The Flow of Liquids in Sewers. G. VELLUT.

(Annales des Travaux Publics de Belgique, 1901, p. 787.)

The problems relative to the flow of liquids in sewers are solved by the equation $v = C\sqrt{rJ}$,

where v = mean speed of flow in metres (3·3 feet) per second;
r = the mean hydraulic radius in metres (3·3 feet): this is the quotient of the liquid area divided by the length of the wetted perimeter;
J = the fall per unit of horizontal length, the metre (3·3 feet) being unity;
C = a co-efficient which depends on the mean hydraulic radius, the roughness of the moistened surfaces, the fall, and the form of the transverse section.

In general the value of C may be taken as:—

$$C = \frac{23 + \frac{1}{n}}{1 + \frac{25 \times n}{\sqrt{r}}},$$

where n = a numerical co-efficient, of which the value depends on the degree of roughness of the walls of the sewer.

The Author, in this Paper, describes a method of solving these equations, graphically, using four tables:—

(1) Mean values of n and $\frac{1}{n}$ for various materials.

(2) Segments of water and mean hydraulic radii at different levels in circular pipes of 1 metre (3·3 feet) diameter, by the aid of which it is easy to calculate the same data for pipes of any diameter.

(3) Sections of water and mean hydraulic radii of oval sewers.

(4) Falls and capacities of circular pipes.

The practical use of the equations and tables is shown by the solving of three problems, the first two relating to circular, and the third to oval section sewers.

One sheet of figures, showing graphic solutions and typical sections of oval sewers, illustrates the Paper.

H. I. J.

Mechanical Handling of Coke at the Dijon and Havre Gas Works. J. LAVERCHÈRE.

(Le Génie Civil, vol. xl., 1901, p. 85.)

The Dijon Gas Works are provided with 4 Brouwer conveyors for dealing with coke, which mechanically perform the following operations: (1) Extinction of the burning coke; (2) its removal; (3) crushing; (4) sorting according to size; (5) storing; (6) sacking.

These works carbonize 25,000 tons of coal per annum, and the conveyors serve 18 furnaces of 9 retorts each. The handling of the coke by machine and by manual labour is, in terms of minute-man per retort, 14·9 minutes for hand-labour, and 8·2 minutes for machine, a saving of 41 per cent. Taking 300 working days per annum, the hand-labour system employed fourteen men and two horses per day, and the machine two men only. The change has resulted in a nett annual saving of £920, which equals, roughly, 9*d.* per ton of coal carbonized.

The Havre Gas Works carbonize 50,000 tons of coal per annum, and are provided with similar conveyors for dealing with the coke. These conveyors are now being utilized to bring the coal to the

retorts by the addition of machinery, which is described under the three heads of: (1) Heaping the coal in bunkers; (2) conveying the coal to the furnaces; (3) charging the retorts.

The details of this machinery and the method of operating same, together with the general details of the machinery for handling and dealing with the coke, are fully described, and are illustrated by eight figures in the text, and a sheet of detail drawings.

H. I. J.

The Electric Lighting of the City of Paraná. C. CALASTREMÉ.

(La Ingenieria, 1900, pp. 750, 763. 5 Figs. and Plan.)

The use of electric light is increasing in the Argentine Republic, in spite of the competition of the Welsbach appliances for gas lighting. The City of Paraná is the capital of the province of Entre Rios, and the electric-lighting works were carried out by the firm of Buxton, Cassini and Company, with Mr. Ernest Danvers as electrician.

The plant installed to begin with will be sufficient to supply 119 Crompton arc-lamps of 8 amperes for the public streets and about 3,000 incandescent lamps of 10 candle-power. The arc-lamps are connected in series of nine on circuits of 440 volts, and the three-wire system will be employed.

Babcock and Wilcox boilers are used, and Westinghouse engines direct coupled to the dynamos, with Wheeler condensers. In the original Articles, plans and cross-sections of the central station buildings are given, and also a plan of the city showing the location of the arc-lamps. At present the length of the longest feeder is 3,270 yards. A similar plant has also been recently put down at Bagé, on the Rio Grande del Sur, Brazil.

E. R. D.

Lighting and Warming by Methylated Alcohol. H. GUÉRIN.

(Le Génie Civil, vol. xl., 1901, pp. 88 and 104.)

An exhibition, organised by the Minister of Agriculture, has been held in Paris to illustrate the industrial uses of sophisticated alcohol, of which the sections devoted to heating and lighting are described in this Paper.

The Author compares the various compounds used both in Germany and France to "sophisticate" the alcohol and render it unfit for drinking purposes; the principal addition being methylated spirit and benzene, or some other hydro-carbon, the effect of which is also to enrich its calorific value. The general mixture used, known as the type Régie, is one hectolitre (22 gallons) of

alcohol, 10 litres (21 pints) of methylated alcohol, and 5 litres (10½ pints) of heavy benzene, the whole costing 36 francs per hectolitre (1*s*. 4*d*. per gallon). A table of the various mixtures compares their destiny and calorific value with petrol and the various grades of petroleum.

The Author then describes various forms of lamps, the greater number of which use the alcohol flame to heat a mantle of the Welsbach type, the general arrangements being similar to petroleum incandescent burners. The section devoted to heating is divided into two classes:—stoves for apartments, and various forms of cooking apparatus; the points considered being the quality of the flame and its calorific value, the facility of recharging, the consumption of alcohol, and the construction from the point of view of security and appearance.

The Author considers that, in spite of the progress made, warming has not as yet achieved so great a success as lighting.

Twenty figures in the text illustrate the Paper.

H. I. J.

On Centrifugal Gas-Separation.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, October, 1901, p. 564.)

The method of separating mixed fluids of different densities by centrifugal force, in the same manner as in the Alpha cream separator, has been applied by Mr. E. Mazza, of Turin, to the concentration of atmospheric oxygen, which, being heavier than nitrogen, tends to move outwards to the circumference of the machine, while the latter remains in the neighbourhood of the axis. In this way, with an expenditure of 1 HP. per hour, 600 cubic metres of air (with 23·2 per cent. oxygen) are concentrated to 200 cubic metres with 35 per cent. oxygen. This is sufficient to burn 23 kilograms of coal, the volume of nitrogen to be heated being reduced by $\frac{5}{8}$, or a saving of 15 per cent., while other economies, due to the smaller size of the fire-place, bring it up to 35 or 40 per cent. over firing with ordinary air. The power required to effect the concentration is about 8 per cent. The analyses of the products of combustion give 9·7 per cent. of carbon dioxide against 6·6 per cent. with ordinary firing. Experiments have been made with lignite and anthracite, both of very inferior quality, when the former evaporated six and the latter about nine times its weight of water, using air with 33 per cent. of oxygen. The anthracite contained 40 per cent. of ash. The process has been specially investigated at Turin by Professor Schäfer of the University of Berlin on behalf of the Imperial German Patent Office, and in trials made by the Italian Admiralty, 1 kilogram of New Pelton Main steam-coal converted 12·15 kilograms of water into steam of 68 lbs. pressure. The same method has also been tried by the

Italian Gas Company of Turin for improving the illuminating power of coal-gas by the partial removal of hydrogen, and it is extremely effective in removing sulphuretted hydrogen. When mixtures of air and carbon dioxide are treated the latter gas is completely separated. H. B.

Standards Adopted for Apparatus for Acetylene.

(Gesundheits-Ingenieur, 31 October, 1901, p. 332.)

The German Acetylene Society, at their Third Annual Convention, held at Eisenach, in August last, adopted the following standards for stationary apparatus for generating acetylene gas:—

(1.) All apparatus for the production, purification and storage of acetylene gas must be constructed of wrought- or cast-iron.

(2.) The size of the producer will depend on the number of burners to be regularly supplied, reckoned at a consumption per burner of 0·35 cubic feet per hour.

(3.) The thickness of the sheet or galvanized iron employed for the above plant must be not less than 0·0295 inch for apparatus for 5 burners; 0·039 inch for from 6 to 30 burners; 0·049 inch for from 31 to 100 burners; 0·059 inch for from 101 to 250 burners; and for over 250 burners the thickness of the metal plate must be 0·078 inch. The thickness of the metal must be such as to guard against deformation of any kind, unless special precautions are taken to insure rigidity of construction, but in no case should the sheet metal used for scrubber, purifier, and driers, &c., be less than 0·039 inch in thickness.

(4.) The bottom, the cover and the man-holes, unless they are made of cast-iron, must in all cases be half as thick again as the other metal-work above specified.

(5.) In the case of cast-iron, the standards to be employed are those prescribed by the German Society of Gas and Water Engineers.

(6.) The joints of all apparatus must be either welded or double-lapped and soldered.

(7.) Apparatus which is not circular in cross-section must be so constructed as to avoid deformation.

(8.) All pipe-connections or stuffing-boxes must be of cast- or wrought-iron, but brass or bronze may be employed for screws, taps or valves.

(9.) Separately erected gas-holders must be constructed of metal of thicknesses (varying in accordance with the contents in cubic feet from 0·039 inch to 0·098 inch) with bottom and top plates half as thick again.

(10.) In those cases, in which the generator serves partly as a gas-holder, the above rules must also be adhered to.

(11.) In the case of apparatus for more than five burners, in which the charge of calcium carbide, which may be added from time to time is not at once converted into gas, the supply of carbide and water must be accessible from the exterior without interruption to the regular working. The available storage capacity must at least be equivalent to 0·27 cubic foot for each normal burner, calculated at 0·35 cubic foot per hour. The outlet for any gas, which is in excess of the capacity of the gasholder, must at least be equal in size to the inlet-pipe to the holder.

(12.) Such precautions must be taken as will render the freezing up of the apparatus impossible.

(13.) The regulations of the German Private Fire Assurance Association must be duly observed, as also those of the police.

(14.) All the dimensions of accessory apparatus, scrubbers, purifiers, etc., as also supply-pipes and taps must bear the true proportion to the assumed output.

(15.) The materials used for purifiers and scrubbers must be such as will be unacted upon by the substances employed in these processes.

(16.) Each apparatus and each gas-holder must bear a plate indicating the maker's name, the place of manufacture, the year when made, and the maximum number of burners to be supplied.

(17.) Each maker must furnish with the apparatus a copy of rules and regulations for use, together with drawings which must be suspended in the place where the apparatus is in operation.

G. R. R.

The Influence of Dust Deposited on Heating Apparatus on the Purity of the Atmosphere. H. C. NUSSBAUM.

(Gesundheits-Ingenieur, 15 September, 1901, p. 271.)

It is a well-known fact that an unpleasant smell makes itself manifest in buildings when the heating apparatus is employed for the first time, even if the temperature does not reach the boiling-point of water. Many reasons have been put forward in explanation of this fact, and it has been frequently asserted that the smell was due to a dry distillation of the dust particles, though this could only take place at temperatures greatly exceeding those likely to arise in the usual forms of low pressure steam apparatus, or those depending on the circulation of hot water. In order to arrive at the real cause of this evil, the Author has recently carried out an exhaustive examination of the different kinds of dust deposited in dwellings and in school buildings. The fine dust, collected with due precautions, was found to consist largely, in some cases almost wholly, of very minutely divided horsedung. Moreover, the dust found on the cold pipes always contained a large proportion of moisture and was rich in micro-organisms.

When the apparatus is first set in operation the warmth induces these organisms to vegetate in great numbers and results in setting free large volumes of ammonia. This gives rise to the unpleasant smell and has an irritating effect on the mucous membrane. In order to avoid the smells, all that is needed is to thoroughly clean the pipes and coils before the fires are lighted.

G. R. R.

The "Sozanthrop"; an Appliance for Saving Life from Fire.

(Annalen für Gewerbe und Bauwesen, 1 November, 1901, p. 186.)

This invention enables a life-saving car or sack to be brought at once by the bystanders to any window or opening of a large façade. The arrangement, which is explained by means of two diagrams, is as follows:—At the highest level, just below the eaves of the top storey and at either end of the building, are two metal pulleys. A small wire life-line is sheaved over each of these pulleys and the ends pass down over a second guide pulley, at a lower level, to the basement of the building, where a couple of coils of thick rope are stowed away, together with the sack or metal car to be used for the lowering of the persons to be saved. By means of the life-line one end of each rope is drawn up over the top pulleys and the other ends of the ropes are attached to the sack or car, which can then be hoisted, if needs be, to the top of the building, and instantly adjusted so as to be brought opposite to any window at any height or at any part of the façade. A hook attached to the car serves to steady it by inserting the same into the window opening, or a fireman can ascend in the car, if desired, in order to bring down feeble or stupefied persons. This invention was approved at the International Exhibition of Fire-Saving Appliances, and, owing to the simplicity of its construction, it deserves to be widely introduced.

G. R. R.

Engineering and Industrial Enterprises at Sault Ste. Marie.

(Engineering News, 9 January, 1902, p. 18.)

This is one of the greatest centres of engineering activity at the present time. St. Mary's river has a fall of 19·3 feet at the rapids in a distance of 3,000 feet, developing 175,000 HP. One power canal and plant is in operation and two others are under construction. The three together will develop 100,000 HP. The Power Company is also erecting factories to utilize this power. The first was a mill for making wood pulp for paper-making, which now produces 150 tons per day. Iron- and steelworks with various

auxiliary plants are already partly finished to utilize the great deposits of iron ore in the Algoma district. In the summer of 1901 about 8,000 men were employed. The expenditure for construction up to the present time has been $10,000,000, and as much more will be required to complete all the projected works. The entire enterprise is controlled by the Consolidated Lake Superior Power Company with a capital of $17,000,000. Under it the water-power plants, the railways, the pulp-mills, the steelworks and other enterprises, are operated as independent concerns. The company has steamer lines from Saulte Ste. Marie running across Lake Superior and Lake Huron, as well as a railway to Sudbury for the nickel ore, and another one to Moose factory on Hudson's Bay for the special timber for the pulp-mill and for the iron ore from the Algoma district. When the projected industrial enterprises on the Canadian side alone are completed they will comprise: (1) a mill for mechanical paper-pulp; (2) a caustic lime plant; (3) the Algoma Iron Works—all these are already in operation; (4) a chemical or sulphite mill; (5) a nickel-ore reduction plant; (6) a complete steel-rail plant; (7) a by-product coke-oven plant; (8) a by-product charcoal plant; (9) an iron and steel pipe and tube plant; (10) an industrial town for the employees at the various works.

Then follow detailed descriptions of the power canals and plants and of the various factories.

The Paper is illustrated by two maps and by four photographs of the works.

C. H. M.

Electric-Power Transmission from Upper Ler Foss to Drontheim. C. Schulz.

(Teknisk Ugeblad, Christiania, 1901, p. 517.)

Upper Ler Foss, one of a succession of falls along the course of the Nid river, is about 5 miles from Drontheim. The height of fall is about 105 feet, and the estimated minimum flow of 265 cubic feet per second would be equivalent to 2,400 HP.,[1] which can be increased to 10,000 HP. by regulating the water-level in Selbu lake, situated higher up the Nid, 17½ miles from Drontheim, 525 feet above sea-level, and 21¼ square miles area. At the fall itself the river is divided into two channels by an island. At head of the left channel the river-bed forms a natural basin, from which are led off to the power-house five pipes of 91 inches diameter for the supply of the main turbines, and a sixth of 33½ inches for those of the magnetizing dynamos. The house, 88½ feet long by 46 feet wide, has been built for four sets of machinery, each of

[1] This is the horse-power (French) stated by the Author; but the figures given represent 3,200 horse-power (French), say 3,150 HP. English.

1,000 HP.; and at a future time can be enlarged for 10,000 HP. The pipes bringing the water to the turbines are 230 feet long, provided with an expansion joint, and also with a waste valve to prevent the water from freezing in the pipes. The turbines already erected are double Francis, which, with 100 feet net height of fall, make 375 revs. per minute; their guaranteed efficiency is 75 per cent. at full and three-quarters load, and 70 per cent. at half. Each is controlled by a self-acting hydraulic regulator, actuated either by hand or by motor from the switchboard. Each turbine drives direct through a fly-wheel coupling a three-phase generator of 850 kilowatts. The guaranteed efficiency of the generators is 93½ per cent. at full load, and 89½ per cent. at half. To the shaft of each is coupled direct an 8-pole continuous-current dynamo of 13 kilowatts at 65 volts tension, for magnetizing the armature of the main dynamo. In conjunction with an intensifying transformer the continuous-current dynamos have likewise to furnish current for charging a battery of Pollak accumulators, comprising 36 elements with a capacity of 216 ampere-hours, discharging in three hours. The primary tension generated at full load is 7,000 volts, about 4,050 volts per phase. The switchboard comprises fourteen panels, of which eight have thus far been fitted up with instruments: namely, two generator panels, two for lighting, two for transmission, one for both the magnetizing dynamos, and one for the accumulator battery and intensifying transformer. All the instruments are for low tension. One of the lighting panels shows the low tension in the city. The current is conveyed across the river above the fall by six conductors of ¼ inch diameter, which are carried on poles, and will together transmit 2,000 HP. with 10 per cent. loss. There will ultimately be fifteen wires of ⅓ inch diameter. The triple-cup insulators on the poles are secured on their bolts with litharge and glycerine.

At a receiving station on the outskirts of Drontheim the overhead conductors from the power-station are succeeded by two underground cables, each containing three wires of 0·05 square inch section. One cable goes to a secondary station, and the other to a feeder in the eastern part of the city. The tension at the secondary station is 150 volts, which is intensified to 550 volts for the double overhead conductors of ⅓ inch diameter, supplying current to the tramway running through Drontheim, a single line 2¼ miles long of 1 metre (3 ft. 3⅜ ins.) gauge, with maximum gradient 1 in 30, and 66 feet minimum radius of curves. There are nine turnouts, each 66 feet long. A six-minute service will be maintained with eleven tramcars, all lighted and warmed by electricity. Each is propelled by two electromotors of 20 HP., which can be coupled either in series or in parallel; and has sixteen seats inside, with standing room for twelve on the platforms; length 24½ feet, wheelbase 5½ feet, weight fully loaded 10·2 tons. Two snow-ploughs, to be pushed in front of the cars, are provided for clearing snow off the line. The supply of current for lighting or for power is intended to be charged either per

annum or by meter. Per annum the charge for lighting will be 11*s*. 1*d*. per lamp, allowing 600 hours alight; power apart from lighting will be rated at £5 11*s*. per electric HP., allowing 3,000 hours. Per meter, both lighting and power will be charged per hectowatt-hour: lighting 0·53*d*., with a minimum limit per hectowatt of the wiring put in; and power 0·20*d*., apart from lighting, with a minimum limit per electric HP. provided for.

A. B.

The Flums Carbide Works.

(Schweizerische Bauzeitung, 1901, pp. 111, 131, 146, 155. 32 Figs.)

Messrs. Spoerry and Company of Flums have for sixty years possessed a water power plant at Schilsbach which supplies energy for a spinning-mill. This plant only uses the lower part of the fall of the Schilsbach, about 492 feet in height, while the upper part would give a fall of 1,082 feet. About 1883 the firm constructed a dam with a capacity of about 1,410,000 cubic feet at the upper part of the stream, and water was impounded during the night and on Sundays, and used to regulate the flow of the stream at other times.

In 1899 the firm decided to use the upper fall also; the volume of the stream was carefully gauged, and it was found that, although the catchment area was only 15·4 square miles, a minimum volume of water of 9·9 cubic feet per second could be depended on even from January to March, and a volume of 28·2 cubic feet per second as a maximum. It was therefore decided to put down a calcium-carbide plant capable of making use of the maximum output. The firm obtained a free concession of the water power from the local authority with the proviso that certain roads should be constructed at the cost of the firm, and the latter employed Mr. Kürsteiner of St. Gall as consulting engineer for both the power and road schemes.

The Author describes the road and dam construction, and maps and illustrations show the general arrangement of the scheme. The upper part of the pipe line is 31·5 inches in diameter, the next portion 27·5 inches in diameter where the pressure is from 103 lbs. to 340 lbs. per square inch, and the lower part 23·6 inches in diameter, so that the maximum water velocity is 9·35 feet per second. The total length of the pipe line is 3,800 yards, and the net fall 1,070 feet. At the foot of the pipe line a powerful spring accumulator is fixed to take up sudden shocks. Provision is made so that the spinning-mill can be worked independently of the carbide factory.

The power house is 72 feet long by 30·2 feet wide, and 2,400 HP. is produced by three turbines each of 800 HP. built by Escher Wyss and Company. These have horizontal shafts,

and run at 500 revolutions per minute with an efficiency of 80 per cent. Full details are given in the original. The electrical plant is by Brown, Boveri and Company. Each turbine drives a three-phase generator producing 5,000 volts with an efficiency of 93 per cent. There is also a small turbine three-phase set of 50 HP. for the lighting of the carbide factory which is 1·1 miles distant. The three-phase current is transformed to 200 volts for power and 115 volts for light. For use in the electric furnaces the high-tension current is transformed to 65 volts, and each furnace uses 2,200 amperes to 2,500 amperes.

E. R. D.

The Wüst Polyphase Motor with Variable Speed.

Drs. Weber and Denzler.

(Schweizerische Bauzeitung, 1901, p. 89. Figs.)

The firm of C. Wüst & Co., of Seebach-Zurich, invited the Authors to make an exhaustive series of tests upon a new type of polyphase motor with variable speed. This motor consists of three parallel and coaxial magnet frames mounted in the same case, the first with 4-pole winding, the second with 6-pole, and the third with 8-pole winding. The rotors are all upon the same shaft. A three-phase current at 50 periods per second is used, and the speeds can be altered from 1,500 to 1,400, from 1,000 to 900, and from 750 to 700 revolutions per minute. The Authors point out that in previous attempts to obtain a variable speed motor it has been usual to alter the number of poles by switching out some of the windings. This new design consists of three separate motors coupled together, and the makers claim far superior efficiency for the latter arrangement. They also claim that by putting two of the motors in parallel double the power can be obtained, and by putting all three in parallel, three times the power can be obtained that could be produced by one motor. The Authors describe the methods adopted in the tests, and the precautions used to get accurate brake readings and satisfactory measurements of the electric energy, and six characteristic curves are plotted for each of the motors used separately, and also similar curves for them used in parallel. The net result appears to be that the 4-pole motor alone fell out of step with a load of 4·5 B.HP., the 6-pole with a load of 4·7 B.HP., and the 8-pole with a load of 4·3 B.HP., the average being 4·5 B.HP.; and as it was desirable that it should be possible to overload a motor 50 per cent. above its nominal output, it was decided that each motor should be called a 3-HP. nominal size. When worked at its normal output the curves show an efficiency of 78 per cent. for the 4-pole and 6-pole and 72 per cent. for the 8-pole part. The starting current is from three to four times the

normal current. When two of the parts are coupled together in parallel 6 B.HP. can be obtained, and the efficiency is 55 per cent., and when all three parts are in parallel 9 B.HP. can be obtained, with an efficiency of 55 per cent. The Authors appear to consider the motor advantageous for cases where sudden heavy loads are put on the apparatus, and the variation in speed is obtained without the use of resistance in circuit.

E. R. D.

Tests of Rotary Electric Transformers.

(Schweizerische Bauzeitung, 1901, p. 127. 6 Figs.)

At the Oerlikon Engineering works an opportunity recently occurred for making elaborate tests of two types of rotary transformers. One was a three-phase-direct machine, consisting of a synchronous motor for 3,500 volts at 50 periods coupled to an eight-pole direct-current dynamo for 260 volts 1,350 amperes at 350 revolutions per minute, and the other, a machine consisting of an asynchronous motor for 6,000 volts at 50 periods coupled to a four-pole direct-current dynamo for 450 volts and 510 amperes at 370 revolutions per minute. As there were several similar sets ready for delivery the tests were made at small cost by the Hopkinson method.

The results are given in the form of curves for all the various factors.

At the end of a ten hours' full load test the rise in temperature of the windings did not exceed 30° C. and the collector 35° C. over the temperature of the surrounding air.

The chief results are given in tabular form, and can also be seen from the curves. The efficiency for the first type at full load was 96 per cent. for the motor, and 95 per cent. for the generator, the output being 350 kilowatts, and for the second type 94·5 per cent. for the motor and 95 per cent. for the generator with an output of 230 kilowatts.

E. R. D.

Electrical Percussion Rock-Drills. Ernst Heubach.

(Zeitschrift des Vereines deutscher Ingenieure, 1901, pp. 1492 and 1526.)

The Author takes up the history of his subject from the earliest inventions up to the most recent practice.

The first attempt to utilize electricity for the production of reciprocating motion without the intervention of mechanism was that of Werner von Siemens, who in 1879 constructed an apparatus

consisting of three solenoids on axes lying in one line, the centre solenoid being fed with continuous current and the two others with alternating currents.

The iron core with the boring tool attached moved backwards and forwards under the influence of the varying magnetic flux.

This method did not prove a success; it required two dynamos, six lines of conductors, was wasteful of energy, and developed considerable heat when working. The alternator had also to be run slow to keep down the frequency, and this occasioned difficulty in the design of the machine.

The patent of Depoeles showed a great improvement on previous efforts. Under it only one dynamo and three lines of conductors are required. The dynamo is a direct current machine with four brushes on the commutator. Two of these revolve at 400 revolutions per minute, with the armature making 1,600 revolutions, the others are fixed.

The leads are arranged so that three kinds of current are produced: continuous current for exciting the field of the dynamo, pulsating continuous current from one of the fixed and one of the rotating brushes, and alternating current from the two rotating brushes. There were three solenoids in the early forms of this apparatus, but later two only were required. Other improvements made included a considerable reduction in the weight of the drilling machine.

A dynamo to produce alternating current of low frequency for use in an electric rock-drill, and also direct current for lighting and other purposes has recently been designed on lines which promise to avoid many of the inconveniences of the Depoeles machines. The armature is wound as for an ordinary continuous current dynamo, and with the usual connections and construction of commutator, direct current can of course be obtained. To produce alternating current from the same armature a commutator is built up on the axis, having a number of bars equal to half the number of coils in, for example, an ordinary ring armature. One of the bars is connected to the coil nearest it and the adjoining bars to the adjoining coils in succession. The consequence is that during a full revolution of the commutator the neutral point has made two revolutions, and an alternating current is produced having a number of periods equal to the number of revolutions of the armature.

The Author gives comparative results from practice as to the working of various percussion drills, and while the electrical is not the most economical it has advantages which will insure its being very widely used.

J. G.

The Charlottenburg Testing-Station.

(Engineering, 10 January, 1902, p. 32.)

This is a brief notice of an establishment, the use and importance of which cannot be too widely known. But it must not be confounded with the Reichsanstalt. It is divided into a mechanical and a chemical section, the whole being under the directorate of Professor A. Martens. There are various departments, each under the management of a separate head; and experimental work is undertaken for official bodies as well as for the general public at home and abroad; but few orders come from abroad, and hardly any from England. The scope of action of this establishment is best seen by an examination of some of the work undertaken. Experiments on porcelain rollers, on the friction of metals and alloys used in bearings, on the sliding friction of leather belts on pulleys; examination of a tempering preparation; standardization of a hardness-indicator and of a mirror apparatus for elasticity tests; crushing tests of hammers; examination of materials to be spread on the permanent-way of a railway; examining rifle-barrels and aluminium cooking-apparatus; tests of natural and artificial stones, betons, concrete, cement, etc.; tests of various kinds of paper, linen, sailcloth, leather, soaps, belts, etc. Oils are tested in a variety of ways. The Customs House applied to the works for a ready means of distinguishing between pitches from petroleum and from fatty substances. Delegates are deputed to attend congresses and exhibitions, etc., and to make special studies.

C. H. M.

The Testing of Metals by Bending on a Cross-cut.

C. Frémont.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, September, 1901, p. 365.)

A brief review is given of the various methods formerly in use for testing metals, previous to the tension-tests which have become general since 1860, when the results were published of the important series of experiments undertaken by David Kirkaldy. All engineers are aware that tensile tests, while they are tedious and costly, fail to indicate certain grave defects, as samples of steel which have given excellent results under tension are found to be so brittle that they break when exposed to a slight shock, or after being subjected to more or less prolonged stress under vibration. Certain tests are given of samples from the Ardennes in illustration of these facts. Special reference is made to some samples of boiler plates which had been destroyed owing to the

brittleness of the steel when they underwent a trifling shock, though the metal had been proved to be very ductile under traction. In another case a water main of large size, constructed of rolled samples of steel plates 0·55 inch in thickness, which had shown a tensile strength of from 26·25 tons to 27·5 tons per square inch and an elongation of 25·5 per cent., was fractured in many places by the mere shock due to the sudden closing of the valves. The steel on further tests was found to be extremely brittle, and the loss occasioned to the contractor was £5,000. Various plans are considered by the Author of conducting the test for brittleness, and the results obtained by static bending are contrasted with those brought about by a shock (a hammer weighing 22 lbs. falling from a height of 10 feet). It is shown by experiment that the test by shock should always be the result of a single blow producing fracture. If a weight falling from a given height fails to break the test-piece, a new test-piece must be operated upon each time, increasing the fall until the sample is broken. If a test-piece breaks at the first blow, the amount of the fall must, in the case of successive tests on fresh samples, be reduced until the shock fails to produce fracture. It is shown that the speed of impact has a great effect in the result obtained. A view is given of a piece of apparatus for testing samples by this method. The method of testing by bending on a cross-cut is then described, and the Author formulates the dimensions of the test-piece, and considers the best mode of making the cross-cut, and the form and size it should assume. Graphic diagrams are given of various tests and enlarged photographs of fractured samples, together with tables of results.

G. R. R.

Experiments on Spiral Springs.

CHS. H. BENJAMIN, M. Am. Soc. M.E., and ROY A. FRENCH.

(Engineering News, 12 December, 1901, p. 446.)

The experiments were made under the direction of Mr. French, and the calculations were worked out by him. An attempt has been made here to determine the co-efficient of torsional elasticity (G) and the safe stresses for different sizes of bar and different ratios of mean diameter of spring to diameter of bar (R). The springs were all made of tempered steel and were compression springs. Every spring was first closed solid, coil to coil, several times by hydraulic pressure, to remove all permanent set. Thus a spring made of $1\frac{5}{16}$ inches bar, 9·25 inches diameter, and 17·25 inches high before closing remained 15·25 inches high after closing, showing a permanent set of 2 inches. The usual formulas for tension and compression springs were used in the calculations. The results are given in a Table, from which it appears

that over 1,700 springs were tested, divided into twenty-seven groups. The diameter of bar used varied from $\frac{1}{2}$ inch to $1\frac{5}{16}$ inches, the mean diameter of spring from $2\frac{5}{8}$ inches to 8 inches, and the ratio of mean diameter of spring to diameter of bar (R) from 3 to 6 (about). G varied from 12,500,000 to nearly 19,000,000, the average being, say, 14,500,000, instead of 12,000,000 as usually adopted. Taking G = 14,500,000, the following values for the torsional stress in lbs. per square inch (S) are obtained for a good grade of steel:—

For bars below $\frac{3}{8}$ inch in diameter	$R = 3;\ S = 112{,}000$
" " " " " " "	$R = 8;\ S = 85{,}000$
" " $\frac{7}{16}$ inch to $\frac{3}{4}$ inch in diameter	$R = 3;\ S = 110{,}000$
" " " " " " " " "	$R = 8;\ S = 80{,}000$
" " $\frac{13}{16}$ inch to $1\frac{1}{4}$ inch in diameter	$R = 3;\ S = 105{,}000$
" " " " " " " " "	$R = 8;\ S = 75{,}000$

C. H. M.

Working Loads for Manila Rope.

C. W. HUNT, M. Am. Soc. M.E.

(Engineering News, 12 December, 1901, p. 444.)

This is a record of the result of an extended experience. The rope is found to be weaker when it is wet. A few months' exposed work weakens a rope 20 to 50 per cent. The results of experience are embodied mainly in three Tables. Table I. gives the tests of efficiency of six-fold tackle; Table II. gives the working loads for manila rope for rapid, medium, and low speeds; Table III. gives the efficiency of various knots compared with the full strength of the rope. The ultimate strengths in column B of Table II. are the results of numerous experiments on full-sized specimens of rope. They refer to ordinary qualities of rope bought in the open market. The proper diameter of pulley-block sheaves for different classes of work given in columns G and H of Table II. is a compromise of various factors affecting the case. An increase in diameter of sheave will materially increase the life of the rope. Thus the life of a rope for transmitting power which goes over large pulleys is much longer than that of a rope working through pulley-blocks. A rope of $1\frac{1}{2}$ inches diameter, transmitting 1,000 HP., running over pulleys 5 feet and 7 feet diameter, 36 feet apart from centre to centre, ran 5,000 feet per minute, making 13,900 bends per hour, or more bends in 9 hours' service than another rope made in its entire life.

C. H. M.

Tests of Fireproof Partitions by the New York Building Department. W. W. Ewing.

(Engineering News, 26 December, 1901, p. 482.)

Fire- and water-tests of sixteen different fireproof partitions were conducted during the year 1901 by the Author, engineer to the department. The object of the test was to record the effect of a fire of 1 hour's duration, with a temperature range of from 500° F. to 2,000° F. and over, followed by the application of a hose stream of water for 2½ minutes. The size of each partition was 14 feet 6 inches × 9 feet 6 inches = 137·75 square feet area. The partitions to be tested were fixed in suitable chambers arranged with fire-grate and draught-flues, and heated with pine and mixed hard cord wood; one side only being exposed to the action of the fire. The partitions were all such as are actually used in fireproof buildings, and of varied construction. Some consisted of solid or hollow blocks without metal binding or framing; in others the blocks were bound together with metal strips or framing; and others again consisted of a double composite metal and plaster construction, with an air-space in the middle. Most of the tests are described in considerable detail, and all the partitions are illustrated by drawings; and drawings are also given to illustrate the testing-chambers and the ground plan of the testing-place. In conclusion, the Author states for what positions the various partitions are suitable, in accordance with the laws and codes regulating the building in New York.

C. H. M.

Comparative Tests of Coal and Crude Oil as Fuel.

J. E. Denton, Stevens Institute of Technology.

(Engineering News, 30 January, 1902, p. 80.)

The tests were arranged with a view to determine the economic fuel-values, care being taken to note everything connected with the boiler-firing that might have a bearing on the practical value of oil compared with coal. The Author's results regarding comparative costs were generalised by him to cover the case of different kinds of coal at different prices. The boiler tested is one of a battery of three horizontal return tube boilers, and was fitted for oil- or coal-burning. It is illustrated by two views in Fig. 1. The arrangement of the furnace for oil fuel is described, as well as the burner itself, and the burner (Williams') is illustrated by Fig. 2. Tests were made to determine the steam raising power and the evaporative power of the oil fuel. The oil-burning apparatus was then removed and similar tests were made with

coal fuel. A Table of results is then given, showing amongst other results that the total dry steam produced by 1 lb. of oil was about 15½ lbs., and by 1 lb. of coal only a little over 9 lbs. The composition of the fuels is given. The time required to raise steam was 59 minutes with oil, and 1 hour 17 minutes with coal. The evaporative power of oil is about 1¾ times that of coal. One fireman could attend to thirty oil burners of 100 HP. each.

A Table is then given of the comparative costs of oil and coal fuels. The oil does not give off inflammable vapour until it is heated above 142° F. There is therefore no danger from this cause in the use of oil.

C. H. M.

Cement Testing, and Manufacture of Cement Wares.

SVEN OFTEDAL.

(Teknisk Ugeblad, Christiania, 1901, pp. 581–3 and 589–92.)

The results of his observations in other countries and of his own experiments are here combined by the Author, who deals first with the necessity of properly supervising the quality of cement, and secondly with the manufacture of the highest class of cement wares.

No general certificate can be accepted in regard to quality of cement; every separate delivery must be tested, and for hydraulic work executed at low water every individual barrel. Where recourse cannot readily be had to a public testing establishment, the fineness of the cement can at any rate be tested without difficulty up to 900 meshes, and a fair idea can thereby be formed as to the grinding of finer qualities. The time of setting should be ascertained by moulding upon glass a number of 3–8ths to 5–8ths inch cakes, and noting when the setting begins and ends. Before testing or using a quick-setting cement, the whole barrel should be emptied and well mixed up together, in order to ensure uniformity throughout; otherwise work may have to be done over again. Tensile test-pieces are best made without ramming the cement in the mould, but by merely filling it up to the edge, leaving it to stand for 24 hours, and then placing it in water, still in the mould. Pure cement can be tested after 7 days; cement mortar, made of one-quarter cement and three-quarters sand (1 : 3), after 28 days. The mould should be made in halves, divided transversely at the waist and cottered together for moulding; for testing, the cotter is removed, and the test piece is pulled asunder without being taken out of the mould. Besides its tensile strength being thus preserved unimpaired for the test, an excellent criterion is also obtained of its solidity; if defective in this respect, the test piece develops cracks in the neighbourhood of the fracture; and

work for which such cement is used will be liable to settlement. The extraordinary effect of the sand in cement mortar cannot be too prominently borne in mind; according to its cleanness and fineness the Author has found the strength of cement mortar (1 : 3) to range from 103 to 263 lbs. per square inch. Hence the same strength can be obtained from 1 : 3 with suitable sand as from 1 : 1½ or 1 : 2 with sand of a different quality. Cement wares fresh from the mould should not be submerged under water, but should only be sprinkled, and exposed alternately to wetting and to air, and, after a while, to the weather, with precautions in winter against frost. Though cement does harden under water, it hardens best under the joint action of both air and water. With test pieces of cement mortar 1 : 3 the Author's experiments gave 292 lbs. per square inch after one month under water, followed by two months in very moist air; 434 lbs. after one month of sprinkling, followed by two months of sprinkling out of doors; and 348 lbs. after one month of sprinkling, followed by two months in a damp place. The sprinkling must be done regularly, mostly twice a day.

Of cement wares there is a great opening in Norway for plain flat roofing-slates, and pan-tiles or channeled roofing-tiles. They should be made of cement mortar not richer than 1 : 3, and be stored for a year before use. They are somewhat porous, but can be rendered sufficiently water-tight by dipping in a mixture of coal tar, asphalt, and carbolineum. They then form a cheap good durable roofing material; and as they do not warp, they keep the roof fire-proof, without holes for sparks. For floor tiles the cement used should be stored for some months beforehand in a thoroughly dry place; the tiles should be subjected to a pressure of 600 to 900 tons per square inch, so as to stand handling immediately afterwards without injury; wasters should be carefully sorted out; and the sound tiles should be stored for a lengthened period. It is the want of sufficiently long storage which, in spite of the raw materials being in every respect as good as those used abroad, has prevented Norwegian cement wares from attaining their due reputation for strength. Washing with hydrochloric acid, however weak, should be dispensed with; it impairs the durability of the coloured surface, which, if unwashed, will wear almost for ever. Mosaic steps and wall slabs are among the finer cement wares offering a wide scope for manufacture. Imitations of granite, sandstone, or marble, can be employed with good effect; they can either be chiselled or be shaped with hydrochloric acid; pillars and balusters can be ground and polished. In Monier construction[1]—cement strengthened by an internal webbing of expanded metal, or of wire netting, or of iron rods or bars—Norway has at present a great deal to learn from other countries. Drain pipes of cement are not yet much used in Norway. But in

[1] Minutes of Proceedings Inst. C.E., 1900, vol. cxlii. p. 288.

Sweden the municipality of Gothenburg in 1890 started works of their own for the manufacture of cement and concrete pipes, on the strength of economical and satisfactory results from trial lengths laid in the two preceding years; those laid in 1889 were oval pipes 4¼ feet high, and cost 22*s.* 6*d.* per yard, inclusive of branch pipes. All sand and broken stone used in the manufacture are carefully washed; the cement and sand (1 : 3) are thoroughly mixed twice over; the stone is added, and mixed twice dry and twice with water; the mixture is rammed in an iron mould; and on removal of the flasks and core the pipe stands for a week, protected from sun and draught by bass mats, which in dry weather are continually wetted. The pipes are then stored for a year before using; and every one of them is tested by a falling weight before carting and laying. During the five years 1891–5 the saving to the municipality by the use of these concrete drain-pipes was reckoned at £1,600, and in addition the cost of the works was almost redeemed.

A. B.

Graphic Solution of Engineering Problems. RODOLPHE SOREAU.

(Mémoires de la Société des Ingénieurs Civils de France, 1901, pp. 191 and 512.)

The graphic solution of equations of two variables, otherwise called calculation by plotting, has latterly undergone considerable development; and by this means results can be read off from formulas, often complicated, which are met with in practical work. Time and expense are greatly economised, particularly in work that has to be repeated, such as retaining walls, aqueducts, embankments, and cuttings. An instance is furnished by the railway from Antananarivo to Moramanga in Madagascar, which included 360,000 cubic yards of earthwork and 60,000 of masonry; by the systematic use of "abaques"[1] two engineers were able to get out the preliminary plans in a couple of days. Plotting in one plane, which was originally employed by Descartes for the graphic representation of equations containing two variables, has now been extended by this method to a higher number of variables; and the Author shows how it can be accomplished with complicated equations containing eight variables and upwards. "Nomography," as the theory of "abaques" is called by Mr. d'Ocagne, who first developed it on a large scale, serves not merely as a method of rapid calculation, but may be also an important aid to the investigation of natural laws.

The principle of the plotting method is explained, for the simplest case of three variables, by supposing each in turn to be

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[1] The word "abaque" or "abacus" is used in its original Latin sense of a table, a desk, or a flat slab; and hence, in modern draughtsmanship, a drawing-board, or a diagram plotted thereon all in one plane.— A. B.

capable of varying between limits. For successive values assigned to the first of the three, the other two variables will represent a group of fair curves, which can be plotted to any extent desired between the limits. Similarly in regard to the second of the three variables; and similarly again with the third. Three groups of curves are thus plotted; and from the intersections of corresponding curves in the three groups, the solution of the problem represented by the equation of three variables can be read off. The complete set of groups constitutes the "abaque" or plotting of the problem. It is sometimes possible to simplify each group by substituting in its stead a single curve; and the three curves so substituted then constitute the plotting. These latter curves are drawn by means of two rectilinear scales used in conjunction; and the four kinds of scales most frequently employed for the purpose are described.

The method is exemplified by no less than eighty plottings, whereof more than fifty have been specially constructed for this paper, which extends to upwards of 300 pages. The first half dozen of the illustrations deal severally with the mode of gauging the flow of a river by the depth of water; proportions and strength of retaining walls for different natural slopes of ground; velocity of penetration of armour plates by projectiles; force of blast in locomotives; volume of truncated cones; and content of casks, tuns, and vats. Without enumerating each individual illustration throughout the whole range of the eighty classified and increasingly complex examples, it may suffice to add that, of the last five in the series, three are concerned with the probability of a relation between the coefficient of the electrical specific heat of metals and their neutral point; and these plottings have given rise to a suspicion that certain physical characteristics of the metals, particularly their electrical resistance and conductivity, enter into the relation with which the three plottings are concerned. The remaining two plottings represent the theoretical consumption in steam-engines.

In spite of the abstract character of the principles on which it depends, the Author considers that this new branch of applied mathematics will prove attractive, alike by the diversity of its applications, by the elasticity of its methods, and by the ingenuity and practical efficacy of its process of investigation.

A. B.

Experimental Determination of the Coefficient of Transmission of Heat. H. Schoentjes.

(Annales des Travaux Publics de Belgique, 1901, p. 749.)

The experiments described in this Paper were made with a view to determine the heat passing through ordinary glass 2 millimetres (0·079 inch) thick, the air both inside and outside being main-

tained at a constant temperature. These experiments were made for various differences between the interior and exterior temperatures, and under the following conditions: (1) the exterior air still and the glass dry; (2) the exterior air still and the glass damp; (3) the exterior air in motion and the glass very wet. Incidentally the heat which traverses mahogany, oak and spruce was also determined.

The apparatus consisted of a frame of wood, 4 feet 6 inches long by 3 feet wide, in grooves of which parallel sheets of glass were inserted, the space between them being 3·3 inches. The temperature of the air in the interior of the space formed by the frame was regulated by an electrical resistance, the current passing through being known. The formula to obtain the coefficient of transmission Q is—

$$Q = \frac{0 \cdot 864\, I^2 R}{(T - E)\, S},$$

where E = exterior temperature.
T = interior „
I = current in amperes.
R = resistance in ohms.
S = the surface of the sheet of glass.

The problem is thus resolved into thermometrical readings and the measure of the intensity of the current passing through the resistance.

The details of the arrangements made for the tests, and particulars of the tests themselves, are given for each day on which they were carried out, and the general results are summed up.

The Author considers that the method adopted by him for measuring the coefficient of transmission of heat through wood, of particularly applicable to the study of the relative efficiency is commercial non-conducting compositions.

H. I. J.

Power-Factor Indicators. W. H. Browne, Jun.

(Amer. Inst. Elect. Engin., Trans. 18, June and July, 1901, pp. 475–500.)

In cases where the power-factor of a station load can be adjusted to unity by varying the excitation of synchronous motors or converters, it is necessary to have some means of ascertaining the exact point of balance. This point is often determined by the minimum reading of an ammeter in the line, or by comparing the volt-amperes and watts. Both these methods are unreliable, for a small error in reading means a large error in balance, when the power-factor approaches unity. This is illustrated by curves.

To give accurate results for large power-factors, measurements

must not involve the cosine, so that either the phase-angle itself or the wattless volt-amperes must be measured.

The Author then describes various forms of phasemeters. Phasemeters measuring the angle directly are: Tuma's, in which a moving system of two coils with their planes at right angles carries the shunt current in one coil, and a current in quadrature with it in the other coil; this system is in the field of two coils carrying the main current; the deflection of the moving system is the phase angle. Anglemeyer, Korda, Hess, Rossi, and Arnò make use of the principle that if two coils, carrying equal currents, are inclined at an angle equal to the supplement of the phase angle between the currents, the resultant rotating field will have a constant value. If the inclination of the coils be varied till this condition is obtained, the phase angle is indicated directly. Phasemeters measuring a function of the phase angle are: Puluy's, in which two electromagnets carrying the two magnets vibrate two mirrors in planes normal to one another; a ray of light reflected from the two mirrors on to a screen describes an ellipse; if one magnet only acts, the ray will describe a straight line; the ratio of the length of this line, cut off by the ellipse, to its whole length, is the sine of the phase angle.

Moreland's and Claude's phasemeters are based on the same principle, but the latter measures the cosine of half the phase angle. A Siemens dynamometer, having two fixed coils and one moving coil closed on itself, measures the cosine of the angle, which is deduced from three readings, one with one current through one coil, a second with the other current through the other coil, and a third with both currents. Arnò's phasemeter is an ordinary dynamometer with an additional moving system consisting of a pair of short-circuited coils in planes at right angles to each other; it measures the tangent of the angle.

In Breitfield's method for three-phase currents, the main coil of an ordinary wattmeter is connected in one line, and the shunt coil, first between this and the second line, and next between the first and third lines; from the two readings the tangent of the angle is deduced.

The General Electric Company's instrument is based on the principle that the ratio of the readings of two wattmeters used to measure the power of a three-phase system varies with the power-factor, and is unity when the power-factor is unity. The instrument consists of two wattmeters, the moving coils of which are attached to the same spindle.

Phasemeters measuring the wattless volt-amperes or E.C. sin ϕ, are: Dobrowolski's, in which fields due to the two currents act on a disk, as in an induction meter, with the difference that the shunt current is in phase with the electromotive force. There is torque on the disk only with a difference of phase, and the torque is proportional to E.C. sin ϕ. The Allgemeine Elektricitäts Gesellschaft's instrument is based on the same principle.

The Author then gives curves and tables showing the results of

experiments on a Siemens dynamometer, a Weston wattmeter, and a Shallenberger meter, and on power-factor meters. The dynamometer was used with a condenser in series with its pressure coil; the Weston wattmeter was used on a two-phase system, and the Shallenberger meter was used with a non-inductive resistance in series with a condenser, in place of its choking coil.

G. H. B.

Furnace Temperatures. W. H. Booth.

(Electrical Review, vol. xlix., August 30, 1901, pp. 338–340.)

To illustrate the actions taking place in the combustion of solid fuel, and the need of refractory furnaces for that process, the following average of 18 analyses of Newcastle coal is taken as a basis:—Fixed carbon 48·84 per cent.; volatile carbon 33·29 per cent.; hydrogen 5·31 per cent.; oxygen 5·69 per cent.; nitrogen 1·35 per cent.; sulphur 1·24 per cent.; ash 3·77 per cent. Calorific capacity of the coal 15,203 B.Th.U. The calorific capacity of amorphous carbon being about 14,647 B.Th.U., that of the fixed carbon in the above coal must be 7,150 B.Th.U., which represents the heat available for transforming solid coal into gaseous hydrocarbons. The 18 lbs. of air per lb. of coal, generally supplied for combustion, must also be heated by it to the temperature of combustion, and the ash and escaping gases also carry away some of the heat. The flame temperature of carbon with the minimum quantity of air (11·6 lbs.) being 4,892° F., that of 1 lb. of the coal with 18 lbs. of air will be $\frac{12 \cdot 6}{19} \times 4{,}892 =$ 3,243° F. The 48·84 per cent. carbon will therefore produce $3{,}243 \times 0 \cdot 4884 = 1{,}584°$ F. This maximum will be reduced in proportion to the different specific heats of the gases in the products of combustion; these being: nitrogen 0·244; carbonic acid 0·217; steam 0·480; hydrogen 3·410; olefiant gas 0·418; marsh gas 0·593. These specific heats vary at high temperatures, generally increasing with increase of temperature. In addition, the latent heat of evaporation of carbon, hydrogen, and oxygen from the solid must be considered. Assuming 7,000 heat units as the latent heat per lb. for all the volatile constituents of the coal, then $0 \cdot 474 \times 7{,}000 = 3{,}318$ units will be absorbed in gasification. This being deducted from the 7,150 total heat units found above, leaves 3,832 available heat units. If the gases were collected unburned, the temperature produced by the fire would have to be below their ignition-point. If half the air-supply were sent through the fixed carbon and the other half supplied to the evolved gases at a later period, that temperature would be doubled. Hence the necessity for regulating the air-supply.

Brick-lined furnaces are necessary to conserve the radiant heat from the incandescent carbon. The following figures are given:—

HEAT GENERATED BY THE COMBUSTION OF 1 LB. OF CARBON IN DIFFERENT STATES.

State of Carbon.	Product of Combustion.	B.Th. U. per Lb.
Diamond	Carbon monoxide	3,915
„	„ dioxide	14,146
Graphite	„ „	14,222
Amorphous	„ monoxide	4,415
„	„ dioxide	14,647
Gaseous	„ monoxide	10,732
„	„ dioxide	20,963
Carbon monoxide	„ „	10,231

Metamorphic Conversions.	Heat absorbed.
Carbon (diamond) to gas	6,316
„ (graphite) „ „	6,241
„ (amorphous) „ „	5,817
„ (diamond) „ carbon amorphous	499
„ (diamond) „ „ graphite	74·7
„ (graphite) „ „ amorphous	424

About half the weight of bituminous coal burns on the grate, and produces half the total heat of combustion; but the vaporisation of the solid fuel absorbs so much heat that only one-fourth is found as sensible heat. The remaining three-fourths are developed between the fuel surface and the extreme range of combustion. Anthracite burns entirely as solid carbon, and hence the high local temperature at the grate bars. The chilling effect of fresh charges of fuel is much less with anthracite than with bituminous coal. Furnace temperatures are always lower than ordinary calculations make them, and many boiler furnaces cause additional loss by interposing very active heat-absorbing surfaces too close to the surface of the fire, thus preventing the proper ignition of the combustible gases.

F. J. R.

Furnace Temperatures. C. C. GARRARD.

(Electrical Review, vol. xlix., Sept. 6, 1901, pp. 382–383.)

The Author takes exception to W. H. Booth's term the "evaporation of carbon" [see preceding Abstract], holding that whilst such an action may occur in the electric furnace it does not exist in ordinary fuel furnaces. What was probably meant by Booth was the latent heat of vaporisation of the volatile hydrocarbons

already existing in the coal, and therefore the proper way of arriving at the loss of heat at the grate by vaporisation of these compounds is to fractionate the coal, and calculate the result from the analysis and known latent heats of the constituents. As to the "latent heat of the vaporisation of carbon" being equal to the difference in the heat of combustion of carbon burned to its monoxide and that of the monoxide burned to dioxide respectively, the methods of combination of the two oxygen atoms in the CO_2 molecule are not necessarily identical, nor can it be proved that they enter into combination with the vaporised carbon with exactly the same liberation of energy. This writer remarks that Booth neglects the effect of dissociation on the maximum temperature obtainable in a furnace, and shows by calculation that Booth's maximum 4,892° F. should be 4,172° F. Although this affects all his calculations, it rather accentuates Booth's point as to the low temperature of the furnace, but this writer considers that preheating the air supply by the waste heat is the rational way of overcoming the difficulties alluded to by Booth.

F. J. R.

Pole-Line Construction for High-Pressure Transmission.

C. O. Poole.

(Journal of Electricity, S.F., vol. xi., August, 1901, pp. 185–195. Paper read before the Pacific Coast Electric Transmission Association, San Jose, June, 1901.)

In this Paper, which is very fully illustrated, the Author gives an account of the system of pole line construction adopted by the Standard Electric Company of California. The poles are of sawn redwood without sap, and vary from 30 feet high, 7 inches square at the top and 12 inches at the base, with 5 feet below ground, up to 60 feet high, 11 inches square at the top, and 17 at the base, with 8 feet below ground. In soft, marshy ground, a sort of Maltese cross arrangement of redwood arms, 8 feet × 8 inches × 2 inches, is spiked on so as to come just below the surface with about 3 feet of turf and earth piled over it. At all angles greater than 2·5° the poles are double constructed and strutted. A truck derrick is used for erection where possible. In very bad ground from one to three piles support each pole. Where supported over water, platforms 4 feet square are built round the bases for construction and repairs. When crossing navigable streams, in order to attain the statutory height of 115 feet above high water, steel towers with redwood tops are employed. The greatest span is 618 feet, with a sag of 19 feet. The cable strains are taken on four to six insulators attached to horizontal arms shaped to the curve of the cable to divide the strain. The main line consists of three aluminium cables, each $\frac{7}{8}$ inch in diameter, and made up of 37 strands. The weight per mile is 2,404 lbs., and the resistance

per mile 0·205 ohm. It is laid right and left hand, and has a tensile strength of 28,000 lbs. per square inch. The factor of safety is 7 at 20° F. Owing to the high coefficient of expansion of aluminium, a 132-feet span, having a sag of 33 inches at 100°, will have perhaps only 13 inches on a cold morning. No. 1 solid aluminium wire is used for tying the large cables, and No. 4 for cables not exceeding 0·5 inch in diameter. The joints consist of right- and left-hand screw sockets, conical-shaped, with the centre or core wire of the cable turned back on itself, forced into the socket, and tightened by driving in a tapered aluminium plug. Their resistance is below that of the ordinary portions. Two-part insulators are employed, the upper half being of porcelain, which resists moisture better, and the lower half of glass, which has a greater dielectric strength. They are tested for five minutes at 120,000 volts, obtained by 12 10,000-volt transformers. Two men can test 30 insulators in 15 minutes. The transformers are connected in groups of three on the low-tension side through insulating transformers, the high-pressure terminals being all connected in series. The pressure is regulated by a rheostat connected in series with the low-tension circuit. The insulator pins are of blue gum sawn into sticks, cleared of sap by boiling, and air dried, after which they pass through a machine which completes the pin in one operation, and finally they are boiled in linseed oil. The pins are driven into the pin-holes with paint simply. A porcelain sleeve covers the base of the pin and projects up under the glass petticoat, an arrangement which prevents weathering, and protects the pin in case of an arc tending to strike from the edge of the insulator to the base of the pin. The cross-arms are of close-grained kiln-dried Oregon pine, treated with asphaltum oil under pressure at a temperature of 250° F. until thoroughly permeated. All poles carry a six-pin telephone arm placed 6½ feet below the power arm. The power line is not transposed, but the telephone wire is transposed every four poles on a single transposition insulator. Provisions are made for opening the power line at several points, in case of trouble, by means of switches contained in specially designed switch-houses.

G. W. de T.

High-Tension Three-Phase Railway in the Valtellina.

H. Martin.

(Génie Civil, vol. xxxix., 1901, pp. 101–106.)

The Italian Southern Railway Company decided last year to adopt electric traction on their Adriatic lines, using accumulators where the traffic is light and a third-rail system where dense. On the 42 kilometres between Bologna and San Felice, accumulator trains have just been started; each bogie carriage, weighing 45

tons loaded, has two 50-HP. motors, and three batteries of ninety-four cells each, and carries sixty people. With the three batteries in series and the motors in parallel, the speed on the level is 75 kilometres per hour.

The Valtellina lines (from Lecco to Chiavenna, with a branch from Colico to Sondrio) have been equipped with a third rail on the Ganz system, using 3,000 volts, three-phase, at the motors. The district served is essentially a manufacturing one, and there is also a large tourist element. The sixty-passenger cars will carry motors to the amount of 300 HP., and will weigh 50 tons, with 2 tons of luggage. They can draw four ordinary coaches up a 1 per cent. grade at 60 kilometres per hour, or up steeper grades at 30 kilometres per hour. Luggage trains will be drawn by 600-HP. locomotives, weighing 50 tons, capable of pulling 200 tons of trucks up a 2 per cent. grade at 30 kilometres per hour.

The long distances between the stations minimize the drawbacks of the alternating system in starting and speed regulation. All metal on the cars, including the metal roof, is carefully earthed, and all apparatus is entirely metal-clad. For equal powers transmitted over the same distance, and with the same drop in voltage, the total weight of copper necessary with continuous current at 700 volts is ten times the weight required with 3,000 volts three-phase. Three hundred amperes is about the maximum current which it is practicable to take from a trolley, and 3,000 volts is therefore necessary for sufficient power to operate trains of the usual size. A device is provided to earth the 3,000-volt trolley wire directly its tension falls owing to breakage.

Energy is supplied from a water-power plant at Mortegno on the Sondrio branch, where three 2,000 HP. turbines are direct-coupled to alternators generating three-phase current at 20,000 volts and a frequency of 15. The transformation to 3,000 volts is effected in nine sub-stations along the lines, whence are fed the two trolley wires, each 8 millimetres in diameter, supported by porcelain insulators from brackets or span wires.

Each motor car carries four motors directly, but flexibly, connected to the axles. At normal speed (60 kilometres per hour), two motors alone are in circuit, receiving direct in their fixed field coils three-phase current at 3,000 volts. The two other motors are only used in starting and stopping and on grades exceeding 1 per cent., when they are connected "in cascade" with the high-tension motors, *i.e.*, the current induced in the armature of the high-tension motor is led into the field of the low-tension motor, whose armature is in turn connected to a liquid resistance. The transformation ratio in the high-tension motor is such that its armature voltage is 300 volts. In cascade, the speed of the train is halved.

The motor cars have bodies 18·10 metres long and 2·70 metres wide, resting on two bogies whose wheel base is 2·5 metres, and whose truck is 4·1 metres long, and is supported from the axle-boxes by ordinary plate springs. The pivots and frame for the

body are further supported by two groups of three double springs. The bogie pivots are 11·5 metres apart.

The two trolley wires over each track are tapped by a special form of double trolley consisting of two copper rollers separated by an insulating block of wood. The trolley arm is raised into contact by a piston actuated by compressed air. The rollers make contact with carbon brushes connected to flexibles. Each car has a double trolley at each end, *i.e.*, 12 metres apart, so that dead sections (which never exceed 7 metres in length) can always be spanned. If the trolley jumps the wires or otherwise rises above the normal level it automatically opens an air valve which lowers it.

The cables from the trolley bases to the apparatus on the cars are rubber-insulated, supported in cylindrical porcelain insulators placed every 10 centimetres inside brass tubes, which are carefully connected metallically to the wheels and the roof, etc., to ensure immediate blowing of fuses in case of leakage. From a distribution box in the operator's cabin circuits are taken through fuses and a primary switch to the motors, and to an 8-kilowatt transformer supplying current to a motor which compresses the air, and lights, heats, and ventilates the car. The primary switch consists of a horizontal iron plate pivoted on a vertical shaft ending in a rack in which engages a pinion worked by a hand crank. Turning this crank raises the plate, which has on its upper side six porcelain-backed metal bolts with steatite heads. These bolts are vertically below six copper sockets sunk in porcelain insulators, three sockets being connected to the motors and three to the collecting apparatus. The bolts enter the sockets with slight pressure, and when withdrawn cause a little rarefaction of the air, which opposes the formation of an arc, which is further prevented by the steatite heads. Reversal of the current to the motors is effected by simple rotation of the lower switch-plate around its vertical axle. A relay in the return circuit to the rails lowers the switch-plate if the current to the motors exceeds the safe limit.

Each bogie truck has a high-tension motor on one axle and a small low-tension motor on the other axle. The large motor will give 150 HP. at full speed. The armature shafts are hollow, and are threaded over the axles, to which they are connected by springs forming an elastic coupling.

The 3,000-volt current goes only to the main motor fields, and the sole operation which has to be done with it is the closing and opening of the primary switch. All regulation is performed on the low-tension induced current by a two-point controller, putting the motors in cascade or otherwise, and an air-valve which regulates the height of liquid in the rheostat. The rheostat consists of a series of small sheets of iron up which an alkaline solution is forced. When the liquid reaches the top, a float operates an air valve, which works a switch short-circuiting the three legs of the armature winding. There are two rheostats per car. All high-

tension apparatus is in a locked case, the key to which is inaccessible as long as the trolley is raised.

The air compressor for the whistle, brakes, and controlling gear is worked by a 5-HP. three-phase motor at 100 volts. An automatic brake is provided, so that when current fails the train is at once pulled up. This will work when an overhead wire is broken or when a section is intentionally made dead to prevent the train passing, thus forming an effectual block system.

E. H. C.-H.

Dielectrics. M. V. Hoor.

(Elektrotechn. Zeitschr., vol. xxii., 5 Sept., pp. 716–719; 12 Sept., pp. 749–751; 19 Sept., 1901, pp. 781–785. Extract from a Paper read before the Hungarian Academy of Science, May 20, 1901.)

The second article contains the results of experiments made to find the variation of the dielectric constant with the slope of potential for paper, paraffin, gutta percha, glass, and micanite. The Author prepared a large number of paper condensers impregnated with various paraffins, and found that very slight differences in the mode of construction and in the materials used q uite altered their dielectric properties. The results are summarised in the following Table, in which the lowest and highest values are given:—

Condenser.	Surface of Plates in Square Centimetre.	Thickness of Dielectric in Centimetre.	Volts per Centimetre.	Capacity m.f.	Dielectric Constant.
Paraffined paper . .	129,300	0·007	55·500 0·528	5·97 6·01	3·65 3·68
" " . .	12,930	0·007	54·400 2·520	0·529 0·55	3·236 3·365
Felten and Gilleaume 500-volt concentric paper cable, diameter of core 1·38 centimetres, length 818 metres	..	0·22	7·480	0·045	2·75
Crown glass No. I. .	1,440	0·065	0·910 22·900 4·460	0·280 0·021 0·0251	17·12 10·7 12·8
Crown glass No. II. .	12,600	0·0193	27·200 1·037	0·40 0·417	6·92 7·22
Megohmit	50,600	0·21	5·950 0·286	0·1085 0·113	5·09 5·31
Gutta percha . . .	106,000	0·0122	41·000 0·491	2·42 2·50	3·155 3·26

The crown-glass condenser No. I. was made by the Author. The ates were washed in ether, heated very slowly to 100° and

cooled very slowly, and the whole condenser immersed in oil under a vacuum. The crown-glass condenser No. II. was made by Mengarini with silver-foil; the condenser when built up was heated in a muffle to the melting-point of the glass, so that the edges of the glass plates beyond the silver fused together. It may be seen from the Table that paraffined paper shows practically no change in dielectric constant with the slope of potential; megohmit and gutta percha show small changes, glass considerably more, while the Felten and Gilleaume paper-insulated cable shows an enormous change, the dielectric constant increasing almost as the slope of potential diminishes. A mica condenser by Elliott Brothers showed no change in the dielectric constant between 5 and 100 volts; the influence of the time of charge was negligible, and the temperature coefficient very small.

The third article deals with the polarisation of the various dielectrics already dealt with, and numerous curves are given for each dielectric at different potentials between the time of charge and the charge. In the paraffined paper condensers the charge increased only some 3 per cent. between 5 seconds and 30 seconds, and at higher potentials only 0·2 per cent.; the discharge was almost complete in 3 seconds. The Felten and Gilleaume cable gave similar results. In the glass condensers the time of charge was far longer, and increased with the potential. In the megohmit condenser it was also long, but diminished with the potential. The difference in the quantities at charge and discharge was small, 2 per cent. at most in the paraffined paper and megohmit condensers, but reached 6 per cent. in the glass condensers.

The last article deals with the energy absorbed in the polarisation period, reckoned from an interval of 5 seconds after commencing the charge. The curve of current and time was taken by a well-damped galvanometer, till the current reached a constant value representing the leakage current of the condenser. The curve was integrated up to this point from the period of 5 seconds, excluding the constant-leakage current. The result multiplied by the potential was taken as the polarization energy. The curves of current and polarization energy, with time of charge, are given for the various condensers. The following Table gives a summary of the results. The column headed "Charge Energy" gives the energy (reckoned from observations with a ballistic galvanometer) in the charge during 5 seconds; the following column gives the ratio of the polarization to the charge energy. The column headed "Ohmic Energy" gives the energy lost in leakage. The energy is expressed in ergs per cubic centimetre of dielectric.

The Table shows that the polarization energy varies from 2 per cent. to 100 per cent. of the charge energy, except in the case of the glass condensers, in one of which it is 750 times the charge energy. The Author could find no general law connecting the polarization energy with the charging potential; assuming it to vary as V^n, n varied from 1·7 to 2·2 in the different condensers.

Condenser.	Volts per Centimetre.	Time of Polarization.	Insulation Resistance.	Ohmic Energy.	Polarization Energy.	Charge Energy.	Ratio.
		Seconds.	Megohms.				
Megohmit	618	200	4,670	0·44	0·94	0·86	1·09
	1,860	220	5,730	5·49	8·12	7·80	1·145
	3,700	140	5,720	13·92	30·10	31·3	0·962
Paraffined paper	18,400	120	6,820	32·30	8·86	485·0	0·0183
	46,200	130	6,920	216·0	75·3	305·0	0·0247
Crown glass No. I	1,980	120	1,970	106·8	28·65	18·57	1·54
	5,980	90	1,930	751·0	99·20	169·5	0·585
	12,000	100	1,545	419·0	676·	680·0	0·993
Cable	1,470	80	69,800	0·133	0·184	3·19	0·0527
Guttapercha	8,680	230	1,260	15·8	16·8	106·4	0·158
	18,000	210	945	83·3	61·0	458·0	0·133
Crown glass No. II	3,350	600	2	102,000	24,300	32·3	750

The Author is occupied in experiments on the effect of the thickness of dialectric on the polarization phenomenon, but in the present article only states that this has a marked effect on the form of the discharge curve, the amount of the polarization energy, and on the loss of energy due to hysteresis.

G. H. B.

Tests of Automatic Stokers.

(Engineering News, vol. xlvi., 7 November, 1901, pp. 345–346.)

This article contains the official report of a comparative test of underfeed "American" automatic stokers firing Stirling boilers, and "Roney" stokers firing Babcock-Wilcox boilers at the works of the General Electric Company at Schenectady, New York. The report is signed by J. E. Denton, Professor at the Stevens Institute, Hoboken, New Jersey, F. W. Dean, and G. H. Barrus, the engineers appointed to make the tests in accordance with the standard code of the American Society of Mechanical Engineers. These tests showed that with coal of an average quality yielding not less than 14,500 B.Th.U. by standard calorimeter, the Stirling boiler with American stoker evaporated 11·889 lbs. gross, or 11·743 lbs. net, water from and at 212° F. per lb. of dry coal, and developed 716 gross HP., or 705 net HP., the rated capacity of the apparatus being 517·5 HP. The Babcock-Wilcox boiler and Roney stoker gave a net evaporation of 11·169 lbs. of water as above.

The cost of fuel per annum in each case, taking coal at $3 per ton of 2,240 lbs., is shown as follows:—

For Babcock-Wilcox boiler—

$$\frac{34 \cdot 5 \times 24 \times 360}{11 \cdot 169} = 26{,}698 \text{ lbs., or } 11 \cdot 92 \text{ tons, costing } \$35 \cdot 76.$$

For Stirling boiler—

$$\frac{34 \cdot 5 \times 24 \times 360}{11 \cdot 421} = 26{,}093 \text{ lbs., or } 11 \cdot 65 \text{ tons, costing } \$34 \cdot 95.$$

The total costs are as follows:—

Costs per HP. per Annum.	American Stoker.		Roney Stoker.
	1.	2.	3.
	$	$	$
Cost of coal	34·95	34·95	35·76
„ repairs	0·77	0·12	0·48
Wages of firemen and helpers	1·44	1·44	1·44
Interest and depreciation	0·38	0·38	0·38
Total cost	37·54	36·89	38·06

Column No. 1 gives repairs according to three months' record in log-book. Column No. 2 gives repairs guaranteed in contract.

F. J. R.

Modern Power-house. J. H. Vail.

(Street Railway Journal, vol. xviii., November, 1901, pp. 478–479.)

Steam-engine efficiency having reached practically the highest point, additional economies must be sought in accessories. The Author proposes a combination of the use of pulverised fuel, superheated steam, and cooling towers for condensing. The first two have been investigated in cement works and at Milwaukee. Regarding the third the Author quotes special experience with the Twenty-sixth Street station of the New York Edison Company, which was designed by him in 1887 and started in 1888. The maximum equipment was limited to 2,600 HP., with the best selection of apparatus then obtainable. Now, however, with the originally designed boiler capacity, the maximum capacity has been increased to 6,000 HP., through improved engines and dynamos, with the application of a cooling tower and condenser system.

Upwards of 500 cooling-tower installations exist, ranging in capacity from 250 to 12,000 HP., the results being in most cases excellent. Results from the open cooling tower at the Plainfield, New Jersey, power-station during July, 1901, are quoted, showing an average vacuum of 25·17 inches and 30° average reduction of temperature of condenser water. With the fan type of cooling tower results show that with an atmosphere temperature of 96° F. and condenser discharge of 130° F., 37° F. of heat were extracted and a vacuum of 24½ inches obtained by passing the water through

the tower. A fan tower is also used at Plainfield, extracts from the log of which are given. The Author advocates giving a liberal margin of capacity in such installations, because a heavy load may come on under adverse atmospheric conditions. The cooling water should be estimated at not less than thirty times the steam consumption of the engine, and two thousand times more air than water will be required. The degree of heat extracted from the water by passing through the tower is affected by atmospheric temperature, humidity, etc., but actual results show a range of from 30° F. to 50° F. reduction of temperature, and a vacuum of 23 inches to 27 inches is readily obtained. There will sometimes be 1 per cent. to 3 per cent. loss of water due to evaporation in the tower, but when the circulating water is kept separate from the boiler feed, that can be made up at slight cost.

F. J. R.

Purification of Boiler Feed-Water.

(Mechanical Engineer, vol. viii., 26 October, 1901, pp. 549–554.)

This is a summary of a section of C. E. Stromeyer's memorandum as chief engineer, to the annual meeting of the Manchester Steam Users' Association. Nine of the principal processes in use for softening calcareous waters were inspected by the chemist of the Association. All the processes are based on the use of lime-water, or milk of lime, for the removal of temporary hardness, and of sodium carbonate for permanent hardness. Most of them are continuous in action, only one of those described being intermittent. The precipitation of the lime salts, and especially of the calcium sulphate, being slow, the different processes exemplify various methods of overcoming the inconvenience of having large settling tanks or of employing filters. These methods are classified as follows:—(1) The treated waters are mixed with old sediment. (2) They are mechanically stirred. (3) They are stirred by air-jets. (4) They are heated. (5) After having settled, the nearly clear fluid is treated with carbonic acid, which dissolves the remaining sediment. The reporter considers 1 and 2, if used with filters, to be fairly satisfactory, but does not favour the use of baffle-plates in the settling towers. He thinks heating, as in 4, expedites the chemical action and the deposit of scale-forming material, but points out that the heating should take place before and not after purification. Nos. 3 and 5 are objected to on account of their charging the water with corrosive agents. Installations of the following systems are described:—The Porter-Clark continous water softener, the Stanhope, the Atkins, the Tyacke, the Wollaston, the Brunn-Lowener, the Desrumaux, and the Reisert processes and apparatus, which are all continuous in action, and the Archbutt-Deely system, which is intermittent.

Diagrammatic representations of the various apparatus are given, and also a few chemical analyses of waters before and after treatment. F. J. R.

Acetylene Motors. H. Cuinat.

(Locomotion Automobile, vol. viii., 26 September, 1901, pp. 616–618. From La Chronique Industrielle.)

Some figures are given relating to the properties of acetylene, and also the results of actual experiments on motors using this gas. An engine tested in 1896 with acetylene gas in the proportion of 1 gas to 20 air, developed 6 HP., with a consumption of 175 litres of gas per HP.-hour. The same engine consumed 516 litres of ordinary lighting gas per HP.-hour at the same power. With acetylene the compression pressure was 8 kilograms, and the explosion pressure 29 kilograms per square centimetre. In the case of a 3-HP. Otto engine tested by the "Gas Motoren Fabrik Deutz," the consumption of gas per HP.-hour was 225 litres at 15° C. The compression pressure was 12·59 kilograms, the explosion pressure 43·6 kilograms, and the final pressure on exhaust 3·87 kilograms per square centimetre. The proportion of gas and air varied from 1 to 25 to 1 to 30.

C. R. D'E.

Methods of Increasing the Power of Petrol Motors. G. Lavergne.

(Locomotion Automobile, vol. viii., 26 September, 1901, pp. 609–610.)

The Author points out that in 1895 the de Dion motor weighed about 36 kilograms per HP., and in 1900 the weight per HP. for the same type of motor had been reduced to 9·4 kilograms. The 16-HP. Buchet motor for the No 5 Santos Dumont flying machine weighs 5·8 kilograms per HP. The following means of augmenting the power of motors are pointed out:—Adding oxygen gas to the explosive mixture; increasing the size of the silencer; and so reducing the loss due to back pressure on exhaust; increasing the pressure of compression, which at present varies from 2·5 to 5 atmospheres, and might possibly be increased to 7 atmospheres with advantage; increasing the speed of rotation, which is limited by the fact that the velocity of the piston must be considerably less than the velocity of inflammation of the explosive mixture. Buchet finds in practice that the limit of piston velocity is between 4·5 metres and 5 metres per second. With higher compressions the piston velocity might be increased.

C. R. D'E.

Electrically Operated Locks on the Dortmund-Ems Canal.

RUDOLPH.

(Zeitschrift Vereines deutscher Ingenieur, vol. xlv., 20 July, 1901, pp. 1009-1017; and 5 October, 1901, pp. 1405-1414.)

There are two electrically operated locks on this canal, the one at Münster and the other at Gleesen. The former is described in this article. The fall of water varies from 6·7 metres to 4·4 metres, and is utilised to drive a turbine giving 11 HP., which in its turn drives a 7-kilowatts dynamo; this furnishes current for the various motors. A small battery of accumulators is also provided. In case of failure of the electrical apparatus the machinery of the locks is capable of being worked by hand. A large number of drawings are given, showing the way in which the motors are geared to the working parts, and the system of control adopted. The lock is 67 metres long, 9·7 metres deep, and 8·6 metres broad, and is provided with auxiliary side basins to allow for the economical use of water. The time required for working the lock is about 165 seconds, and the energy consumed is on an average 278 watt-hours, including lighting, etc. The amount of water taken by the turbine is 1·4 per cent. of the amount required for the working of the lock.

W. H. S.

Electrically Driven Pumps at Horcajo. F. HEERWAGEN.

(Zeitschrift Vereines deutscher Ingenieure, vol. xlv., 2 November, 1901, pp. 1549-1559.)

The mine of Horcajo is in the Spanish province of Ciudad Real, and, since 1855, has been noted for its silver containing lead ore. The presence of water has always necessitated pumping, and the original machinery has now been replaced by high-pressure centrifugal pumps, made by Sulzer, which are directly connected to three-phase motors. The electrical plant has been supplied by Brown, Boveri and Co. The generators are 20-pole machines, with an exciter on the same axis, which give 1,000 volts at 270 revolutions per minute. The output is 300 HP.; with a power-factor of 0·8 the efficiency is 93 per cent. Three more alternators of the same kind, but of 400 HP., have lately been added. They are all driven by Sulzer engines. The motors are six-pole, and give 250 HP. at about 900 revolutions per minute, with an efficiency of 94 per cent., the power factor being 0·85. They are directly supplied at 1,000 volts. The working of these motors has proved extremely satisfactory. No difficulty has been experienced at starting, and there has been no trouble with respect to insulation. Current is supplied by steel-armoured, lead-covered cables supported on the walls of the shaft. The article is illustrated by many plans and diagrams.

W. W. H. G.

Erection of Overhead Power-Lines. LOPPÉ.

(Soc. Int. Élect., Bull., vol. i., August, September, October, 1901, pp. 455–484.)

The Author considers, in the first place, the effect of variations of temperature in causing both elongation and change of elasticity, giving formulæ and tables for determining—(1) the length of the wires in times of the sag and the span; (2) the change of sag of copper wires, firstly, in times of the temperature change, of the initial sag, and of the initial tension; and secondly, in times of the change of pressure per metre run, of the initial sag, and of the initial tension. The effect on the impedance of the line, of the distances between the wires, is then discussed, and Tables are given, due to Blondel, which were originally published in 1894 in *l'Éclairage électrique;* after which the Author proceeds to consider the principles determining the best length of span under given circumstances, and Tables are given to facilitate the evaluation of the formulas for wires of copper and aluminium, allowing for a wind-pressure of 125 kilograms per square metre of superficial area of the wires. This pressure will be about 0·60 of that on a plane surface.

Increase of span involves, *cæteris paribus*, a corresponding increase of sag, which is limited by the greatest admissible height of the poles, and, on account of the necessity of preventing contact, by the distance between the wires. In American practice the sag is not allowed to exceed double the latter distance, but the Author states that no trouble has arisen from this cause in the case of the Paris and Bordeaux telephone line, consisting of a pair of wires 4·5 millimetres in diameter, separated by an interval of 0·65 metre, and having spans of from 70 metres to 80 metres, and therefore a sag exceeding 2 metres. The Author, as an example, gives in detail the calculations for a three-wire three-phase line of copper wire 5 millimetres in diameter, with a maximum allowable tension of 8 kilograms per square millimetre, and under given conditions as to maximum wind-pressure, temperature limits, and possible accumulation of snow or ice. The necessity is insisted on of diminishing the tension at which the wires are erected, when, owing to crossing other lines, or for any other reason, the span has to be decreased, and advises its decrease in the same ratio as that of the span. In conclusion, the Author discusses, by the aid of Tables of the mechanical and electrical constants of copper, aluminium, and various kinds of bronze, the relative advantages of these materials for overhead line wires. With copper costing, as at present, 2 francs 20 centimes per kilogram, and aluminium 4 francs per kilogram, it is shown that both the best length of span and the cost will be about the same, whichever material be employed. With regard to dissipation of heat, aluminium is at a disadvantage compared with copper, but the use of bronze is strongly advocated in preference to either, even for wires of large diameter.

G. W. DE T.

Central Power Station of Birmingham, Ala., U.S.A.

J. R. WILLIAMS.

(American Electrician, vol. xiii., September, 1901, pp. 421–424.)

System: Three-wire direct current at 125 volts, and series arcs for lighting; direct current at 500 volts for traction; single-phase and monocyclic alternating current for supplying the remoter districts. The boiler rooms contain 24 horizontal return-tube boilers, working at 120 lbs. per square inch, and feeding a single wrought-iron header 14 inches in diameter. The feed-water is heated by Wainwright heaters. The furnaces are fired by hand. The engine-room contains 10 simple non-condensing Corliss engines, and one single-valve automatic engine; fuel is so cheap that compound condensing engines offer no prospects of economy. Six of the engines are coupled in pairs; two of these sets have cylinders 24 inches × 48 inches, and drive two 875-kilowatt railway generators at a speed of 82 revolutions per minute; the third set has cylinders 20 inches × 30 inches and drives two 200-kilowatt lighting generators, working at 125 volts each, at 150 revolutions per minute. Four other engines have cylinders 21 inches × 48 inches, 18 inches × 42 inches, and 26 inches × 48 inches respectively, and drive various generators by means of counter-shafting. The automatic engine has a cylinder 20 inches × 20 inches, and drives direct two 100-kilowatt 125-volt dynamos at 200 revolutions per minute. Open arc lamps are used for public lighting, and enclosed arcs for private lighting. For the supply of the neighbouring towns, part of the alternating current is transformed up and transmitted at 5,000 volts; it is distributed at 1,040 volts. A 5,000-volt three-phase alternator is to be installed for the supply of a railway line to Bessemer, 12 miles distant; transformers and rotary converters will be installed in sub-stations for this purpose.

A. H. A.

Malakoff (Paris) Electricity Works. C. DANTIN.

(Génie Civil, vol. xxxix., 5 October, 1901, pp. 361–365.)

These works are intended to supply current for a tramway system of a total length of about 40 kilometres within and without Paris. Inside the city the cars are run by means of accumulators, which are charged through a trolly from aerial cables erected along the parts of the routes which lie outside the walls, the cars being run from the overhead supply while the cells are being charged. The general construction of the station and of the lines

has been carried out by the French Thomson-Houston Company. There are six Babcock and Wilcox boilers, arranged in pairs, working at 11 kilograms per square centimetre, and each capable of evaporating 2,900 kilograms of water per hour, or 3,100 under forced draught. There is also a Green's economiser of 400 square metres heating surface; two Worthington feed-pumps, each capable of supplying the whole of the boilers, and an electrically-worked pump, of the "Thirion" type, of similar capacity. There are in present use two direct-coupled steam sets, each of 500-kilowatts capacity, and a third is to be shortly erected. The generators are 8-pole, compound-wound machines, of which the full rated load is 910 amperes at 550 volts; they were built by the Société des Établissements Postel-Vinay. They present no special features of interest. They are stated to be capable of working for 24 hours continuously on full load with a rise of temperature not exceeding 50° C. for any part of the machine, and, after this, an overload of 50 per cent. for one hour with a rise of not more than 60° C. The efficiencies given are:—One-quarter load, 89·7 per cent.; half-load, 92·8 per cent.; three-quarter load, 93·8 per cent.; full load, 94 per cent.; 50 per cent. overload, 93 per cent. The engines are of the "Allis" type, built by the Société française des Constructions mécaniques. They are of the horizontal, compound, condensing type, with Reynolds-Corliss valve gear, running at a mean speed of 95 revolutions per minute. The diameters of the cylinders are 508 millimetres and 1,016 millimetres respectively, the stroke being 1,220 millimetres. The connecting rods are of exceptional length, being six times the crank radius. Each engine is provided with two Porter governors, one of which regulates the steam admission to each cylinder simultaneously; the speed of the engine can be varied while running by an adjustment of this governor. The other is a safety device to cut off steam if the engine should run away. The fly-wheels are 6·1 metres external diameter, and weigh 40 tons (French) each. Figures are given of a 6-hours full load test in which the steam consumption came out at 6·26 kilograms per I.HP.-hour (French). In addition to the main engines and generators, there is a small vertical high speed set of 70 kilowatts for works, lighting, etc., which can also be used, if necessary, to excite the large generators. The switchboard consists of nine marble panels in an angle-iron frame; two panels for the two large dynamos, one for the small one, one testing panel, four for the feeder circuits and one for the works service. The equipment of the switchboard is of the usual character and does not call for detailed description.

B. P. S.

Power Transmission at Crottorf, Saxony. R. Apt.

(Elektrotechn. Zeitschr., vol. xxii., 28 November, 1901, pp. 984–988.)

This station has been built by the Helios Company for the purpose of supplying current in an agricultural district. Some part of the power, to the extent of about 500 HP., is derived from a waterfall 2·7 metres high. Three turbines, each giving 185 HP., and running at 54 revolutions per minute, are connected to a common shaft by toothed wheels, to which also a three-phase generator is directly coupled. The generator can also be driven by steam, if necessary, the connection being made by a form of friction coupling. A second steam set of similar capacity is also provided. Each three-phase generator has an output of 500 kilowatts at 7,000 volts, running at 125 revolutions per minute. Steam is furnished by five Cornish boilers, built by Paucksch, each being 10·14 metres long and 2·2 metres in diameter. The power is distributed over a radius of 15 kilometres in twenty-seven villages. Usually alternate current is supplied, but in some of the larger villages the lighting is carried out on the direct current system. This is worked as follows: A battery of accumulators is installed, and is charged during the daytime by means of a motor-generator. The lighting current is then provided by the cells, which discharge in parallel with the motor-generator. But even in these places power is supplied for motor purposes by three-phase current, the distribution throughout being effected on the usual overhead system.

W. H. S.

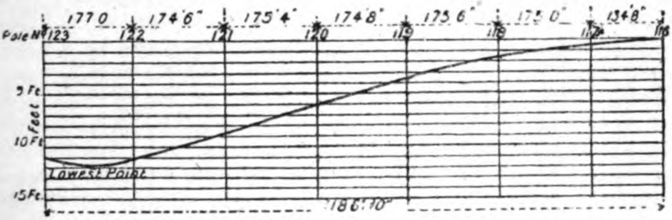
Tests of Roller Bearings. W. H. Booth.

(Tramway and Railway World, vol. x., October, 1901, pp. 557–562.)

The Author points out that by the use of wheels and axles the tractive resistance on rails is decreased some 98 per cent., so that about 2 per cent. only, representing some 11 lbs. or 12 lbs. per ton, is the reduction that is possible by the use of a perfect roller bearing. With the rapid acceleration required in tramway practice, the amount of starting current that can be saved by roller-bearings forms a very small proportion of the whole. On ascending grades the extra power will be practically the same whether plain or roller-bearings are employed. On descending grades the car may take less current on very gentle slopes, but on steeper gradients braking will be necessary, and this will be greater with roller-bearings than with plain ones, with greater wear of wheel rims and shoes, but less axle wear. Outside these points the economy will simply be equivalent to the power saved on a level road.

In making the tests described in this Paper a straight section of

line was selected with a slope sufficiently flat to prevent a car from acquiring a dangerous rate of speed, when started from rest at the top of the slope, and allowed to drift freely downhill under the influence of gravity. The starting effort was that due to a rapid snatch, on and off the first notch, of the starting handle. The post distances and the slope are shown in the accompanying diagram. The times of passing each post were noted, and the distances measured between the posts. One set of tests was made by allowing the cars to drift down the slope under the action of gravity,



and with similar conditions of weather, load, etc. The cars tested were exactly similar, except that one had ordinary white metal bearings, the other the bearings to be tested. The load was about 1,800 lbs. Owing to the speed of the record as varying with the amount of winding up of the springs, the record strips did not correspond in length with the actual times, but this introduced no serious error, as the areas of the diagrams were measured by a planimeter, set, in each case, to the length of the diagram, so as to measure the mean height. The results are given in the accompanying Tables.

TABLE I.—ROLLER BEARINGS, CAR A.

1	2	3	4	5	6	7	8	Remarks.
No. of Notch.	Length of Paper.	Apparent Equivalent Time.	Actual Time.	Maximum Amperes.	Volts.	Average Amperes of Current.	7 × 4 Amperes × Time.	
	Inches.	Seconds.	Seconds.		500		Amperes Seconds.	
1	6⅜	127·5	137	6	Voltage on each day practically identical.	4·700	643·8	
2	7⅜	147	133	5		3·375	448·8	
3	7¼	145	128	5		3·870	495·3	
4	7¼	145	127	5		3·437	436·5	
5	6⅜	127·5	110	8		6·060	666·6	
6	5¼	105	87	19		12·500	1087·5	
7	4¾	95	82	21·75		12·900	1058·0	
8	5⅛	102	88	21·5		12·000	1056·0	Controller put slowly on.
Drift	6¼	125	112	—		—	—	
,,	5⅞	117	102	—		—	—	
,,	6⅜	127½	110	—		—	—	

TABLE II.—WHITE METAL PLAIN BEARINGS, CAR B.

1	2	3	4	5	6	7	8		
No. of Notch.	Length of Paper.	Apparent Equivalent Time.	Actual Time.	Maximum Amperes.	Volts.	Average Amperes of Current.	7 × 4 Amperes × Time.	Economy of A over B.	Remarks.
	Inches.	Seconds.	Seconds.				Amperes Seconds.	Per Cent.	
1	8	160	155	7	500	5·810	900·2	24·48	Brake probably on slightly.
2	6⅞	137	139	7	Voltage on each day practically identical.	6·000	834	46·18	
3	6 3/16	124	133	7⅛		6·125	814·4	39·18	
4	6⅝	132	130	7⅛		6·125	796·2	45·18	
5	5⅝	112	115	9		7·500	862·4	22·7	
6	4¼	85	86	18½		15·800	1301	16·41	
7	4⅛	85	84	20		15·200	1277	17·15	
8	4⅜	87	84	21·5		15·125	1270·8	16·9	Controller put slowly on, but more quickly than on car 2.
Drift	10	200	194	—		—	—	—	Brake probably on slightly.
,,	7⅝	152·5	160	—		—	—	—	
,,	7½	150	157	—		—	—	—	

It will be seen that the roller-bearings had very little effect on the time occupied in each uphill run. The power, however, is considerably less in the case of the car provided with them. If for each car the sum be taken of the amounts of current in notches 2, 3, 4, the mean difference is 2·523 amperes, which appears to be the saving due to the roller-bearings, and approximates closely to the 2·742 amperes found as the mean difference of the two cars in notches 6, 7, and 8, these latter being controller positions with the two car motors in parallel.

In the series running it works out to 354·7 ampere-seconds saved in a run of 1,187 feet, which means in this case nearly 4 HP., corresponding to an extra traction resistance of about 15 lbs. per ton. The total weight of each car was about 7½ tons.

The average current taken per car on this line is about 14 amperes, so that a saving of 2½ amperes is about 17 per cent. This apparent economy will, however, be reduced in the ratio of the time of standing and of downhill running with no current, to the total time. The Author estimates, therefore, the maximum economy, on the basis of these tests, as not exceeding 10 per cent., while it may fall as low as 6 or 8 per cent.

G. W. DE T.

Block-Signal Apparatus.

(Electrical World and Engineer, vol. xxxviii., 28 September, 1901, pp. 500–502.)

This Paper describes the mechanism in the post devised by C. W. Coleman, of the Hull Signal Company. The post carries home and distant signals. An electromotor is geared by a double set of reduction-gears, to the axle carrying the crank to which the up-and-down rod of the semaphore is connected. The gears are kept from revolving backward by a ratchet. The crank operating the up-and-down rod of the signal is not permanently fastened to the axle upon which it turns, but is free to turn independently of the gear, except when held by an electro-magnetic clutch. When a signal is to be pulled to "clear," the motor and clutch circuits are closed, and when the signal is at "clear," a cam switch connected with the rod opens the motor circuit, and the signal arm is kept in position by the clutch, and a ratchet acting on the motor gearing. To put the signal to "danger," the clutch is released, and the rod, which is heavier than the arm, overbalances the latter and brings it back to its normal position. There are cranks and clutches for two signals. The motor is a $\frac{1}{8}$ HP. Crocker-Wheeler. The power required for clearing a signal, about 4 amperes at 6 volts for 10 seconds, is obtained from caustic potash batteries. Half the amount of energy is required as compared with early types, with the same factor of safety on the counterweight.

E. O. W.

English and American Railway-Signalling. J. Pigg.

(Electrical Review, vol. xlix., 27 September, pp. 503–505; 4 October, 539–540; 11 October, 582–583; 25 October, 663–664; and 1 November, 1901, pp. 701–705.)

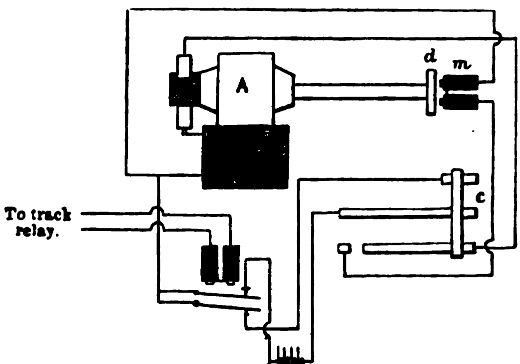
The Author describes the development of railway signalling in America, and contrasts the methods now in use in that country with those employed in England. One of the most general is known as the Controlled Manual System. One operator releases the lever of the other, but the process is governed by the train. The releasing apparatus is arranged so that it can be operated but once for each train passing through the block controlled by it, and then only on condition that the signal of the next succeeding block is restored to danger behind the previous train. Formerly the train worked a treadle, but the latter suffered from the heavy blows. Now the "track circuit" is used. Two insulated parallel rails form an independent circuit with a small Daniell gravity battery and a relay. When a train passes the current is diverted from the relay, and the tongue of the latter influences the signal circuit. There is special mechanism by which the lever of, say, "A's" signal is locked in the danger position by the armature of

an electro-magnet controlled and operated by "B." A special circuit is erected between those points for the operation of the apparatus, and at each place an indicator is provided, which shows "clear" when neither has given permission to lower the other's signal, and "blocked" when one of them has done so. At "A" the special circuit includes the electro-magnet only, the armature of which locks the signal lever. At "B" the circuit is completed through the tongue of a relay operated by the track circuit relay, and also through a "plunger" or circuit breaker. The effect of "plunging" is to break down the special circuit by which the lock is operated, and it remains in this condition until the train signalled passes on to the track circuit, which, of course, is outside of the "block." Until the train has passed on to the track circuit, and remade the locking circuit, further use of the plunger has no effect, and the operator at "B" is thus prevented from releasing "A's" signal for a second train, even if he inadvertently goes through the operation of plunging.

A purely automatic system is that known as the "overlap." In this arrangement the signal at the entrance to a section is kept at danger by the train in the block until it has passed the signal governing entrance into the succeeding block, a certain predetermined distance, both signals being held at danger during the time the train is on the overlap section. A supplementary signal to those already referred to is known as the "distant" or cautionary signal. This signal is essentially a repeater, in that it indicates the position of the "home" or stop signal at the entrance to the block ahead. The overlap system, since it ensures the placing of two signals to danger behind a train after it has passed into the next block ahead, is considered to minimise the risk of collision with a succeeding train which has passed the first of the two signals referred to. This action is accounted for by the rule that, where automatic signals are in use, trains may pass them, when at danger, at caution, after a stop of one or more minutes, as the rule requires. Hence the overlap system enables two signals to be kept at danger behind the first train until the latter is some distance within the protection of the last one. The disadvantage is that drivers may be tempted to pass signals carelessly when at danger, when aware that the previous train may be actually out of the block governed by the signal.

In the most recent practice signals are operated by compressed air, separately provided and supplied, as in the Westinghouse system; or by electric motors, as in the Hall system. In the former the track relay governs the valves of a compressed-air motor through the medium of an electro-magnet. The positive action of the motor duly lowers the arm. It is returned to danger by means of a counter-weight. The Hall system provides for the operation of "distant," "home," and advanced or starting signals in places where it is desirable to draw a train forward for shunting or other purposes before the block ahead is clear of the preceding train. Besides this, warning bells are provided at all

switches in a section. Signals are operated by electric motors of about $\frac{1}{8}$ HP. The motor is attached to the signal above the counterweight, which it works by means of a stranded wire cable, the other end of which is attached to a drum in gear with the armature shaft, so as to effect a reduction of speed in the ratio of 25 to 1. The arrangements are shown in the accompanying diagram. A is the motor, *m* a magnetic brake acting upon an iron disk, *d*, attached to the armature shaft, and *c* is a commutator for altering the circuits automatically. The commutator is driven by a worm and gearing on the drum shaft. When the relay is first energised, the commutator is as shown, and current passes through the motor, which lowers the arm. As the motor runs, the commutator changes the circuits, in effect, as if the vertical passed gradually to the opposite end, breaking the motor circuits, and passing the current from the battery through the brake coils—which are of high resistance and take comparatively little current—instead. The magnetic brake draws up the motor, and holds it



after the signal arm has been lowered. The signal is raised to danger again, when the armature of the relay is released, by the counterweight, and the commutator resumes the position shown by the rotation of the armature under the action of the counterweight. In this position of the commutator the motor circuit is short-circuited as long as the relay is not energised. Hence the current, generated by rotation of the motor armature by the falling counterweight, acts as a brake, and ensures the signal taking its position without undue shock.

Attempts have been made to cause a signal to physically prevent the entrance of a train into a block already occupied, by independent operation of the air-brake; for instance, by a glass tube above the engine, which is broken by the impact of an arm projecting from the signal, or by a special projection on the track being made to close the throttle-valve; but they have not generally met with success.

Methods and Systems of Signalling in Use in this Country.—The

essential difference between British and American methods consists in the control of the signalling. In the States, in the higher development of signalling, control is exercised by the train itself by virtue of its position. With trifling exceptions, the highest development in this country is comparable only with the controlled manual in America. There are reasons why the use of automatic signalling should be more pronounced in the United States than in this country. Automatic signalling, whilst the ideal system for lines where long distances have to be run between diverging points, fails in that it exercises no selective action, and is therefore unsuitable for use at junctions. In this country junctions are numerous, and the operations at such points must necessarily be selective. There are, however, many places where automatic signalling might be used, though they do not necessarily form consecutive sections.

E. O. W.

Electrolysis by Earth Returns. W. Leybold.

(Electrical Review, vol. xlix., 20 September, 1901, pp. 492–493.) Paper read before the Glasgow Engineering Congress.)

Electric currents were detected in water pipes near Durlach, 6 kilometres from the nearest generation-station, which were certainly not due to external influences. Such currents can only be due to voltaic action between the iron and the lead which is used for jointing. The Author gives an account of the destruction of gas-pipes at Hamburg, where the ground contains 0·0006 to 0·04 per cent. of sodium chloride. The electric trams were started in 1894, and were completed in 1895. In the latter year, corrosion of the wrought-iron pipes was discovered at points where they passed under the rails. The 1-inch pipes are covered with canvas soaked in boiled tar, but this method of protection does not seem to be very effective; in fact it favours the corrosion when once this has begun, because blisters form between the iron and the tar, containing saline liquid which is favourable to electrolysis. No corrosion has been observed in the pipes of cast-iron. The destruction has been remedied by laying down return-feeders which have reduced the pressure between the rails and the gas-pipes in one of the streets from 5 volts to 0·45 volt.

W. R. C.

Cable Speed-Rate Conversion Tables. E. Raymond Barker.

(Electrical Review, vol. lxix., 22 November, 1901, pp. 865–867.)

Tables of multipliers by which statements of telegraphic speed, whether in siphon recorder or in Morse code, may be reduced from one mode of expression to another with due regard to the varying

space factor. A formula is constructed and forms the basis for the tables as follows:—The element (e) is the fundamental unit, where each contact (siphon recorder) = $1e$, each *dot* (Morse) = $1e$, each *dash* (Morse) = $3e$, each space between contacts = $1e$, and each space between words = $7e$. The number of elements per letter, denoted by v, has for traffic purposes been shown to be 7·16 for recorder, and 9·12 for international Morse. And x, the number of words N letters signalled per minute, being equal to the ratio of the number of elements signalled per minute, to the number of elements per word of N letters, allowing for spaces between letters and words, is determined from the following equation, in which W is the number of words, and L the number of letters received in T minutes:—

$$x = \frac{\{Lv + 4(W-1)\}\frac{1}{T}}{vN + \frac{4}{vN}}.$$

For practical purposes, a sufficiently close approximation is obtained by writing—

$$x = \frac{(Lv + 4W)\frac{1}{T}}{vN + \frac{4}{vN}}.$$

E. O. W.

Small Elastic Displacements. F. Kohlrausch and E. Grüneisen.

(Preuss. Akad. Wiss. Berlin, Sitz Ber., vol. xlvi., 14 November, 1901, pp. 1086–1091.)

Reference to the work of Bach is made, in which the connection between stress and strain is expressed by the formula $\epsilon = A\sigma^m$, where ϵ is the relative extension or contraction, σ the force per unit area, and A and m are constants of the material. This law, or a similar one with a series of powers, is said to express the connection of stress and strain more accurately than the old law of simple proportion. The importance of such a formula for technical purposes is admitted, but the theoretical importance claimed by Bach is doubted. The validity of extending the supposition at all beyond the experimental range is denied, and the need for investigation, especially in the low values, is insisted upon. Experiments by the Authors upon the flexure of rods of cast-iron, wrought-iron, brass, and slate are given. In these an optical method is used, and the strains are measured with great exactitude. For wrought-iron the law of simple proportion is found to hold. A less complete adherence to this was found in the case of brass, but the deviation was much less than that found by Bach. Slate, within the limits

experimented upon, acted as a completely elastic body, and showed an unexpectedly high elasticity modulus. For grey cast-iron, agreement with Bach's results is found. The formula $\frac{x}{y} = A + B\sqrt{x}$, where x and y are the stress and strain, A and B elastic constants, is suggested as satisfying the results more closely than Bach's formula. The question of discontinuity in the passage from extension to compression is also touched upon.

J. W. P.

Critical Velocity of Liquids. H. T. Barnes and E. G. Coker.

(Physical Review, vol. xii., 1901, pp. 372–374.)

H. T. Barnes showed[1] that if water be heated while flowing through tubes at velocities less than the critical velocity, so that the motion is in the form of parallel stream-lines, then the distribution of heat is not uniform; that where the heat is applied to the outside of the tube, only a few layers of the water in direct contact with the tube will be heated, the influx water passing through the centre unheated; and that where the heat is received from a central wire, the hot water flows along the wire, leaving the sides of the tube unheated. For flows beyond the critical velocity, the flow is eddying and sinuous and the distribution of heat throughout the water-column is uniform. The Authors now find that the sudden passage from direct to sinuous motion is very sharply determined by placing the bulb of a sensitive mercury thermometer in the path of the moving column of water just as it emerged from the tube; when the motion becomes sinuous, even for an instant, the mercury-column shoots up, and the break-down of the stream-line motion thus shows the attainment of the critical velocity.

A. D.

Action of Direct-Current Armatures on Alternating Currents. M. Latour.

(Écl. Électr., vol. xxix., 23 November, 1901, pp. 294–300.)

The Author gives a theory of the properties which he has discovered of direct-current armatures when traversed by alternating-currents. These properties were called in question by Leblanc, who, from *à priori* considerations, gave reasons for doubting them. The Author quotes a letter from Boucherot, who states that he has experimentally proved that the impedance between two neigh-

[1] Proceedings of the Royal Society, vol. lxvii., 1900, p. 238.

bouring brushes pressing on the commutator, when connected to a polyphase system, is a function of the speed of the armature. He took the drum-wound armature of a four-pole direct-current dynamo and placed it in the stator field of an induction-motor, the windings of the stator being left open-circuited. With direct-currents the resistance between No. 1 and No. 3 brush, or between No. 2 and No. 4 brush, was 1·8 ohms. The brushes were then connected to a two-phase system of frequency 25. The impedance between the brushes was found to vary from 15 ohms at rest to about 2 ohms at synchronism, and at higher speeds it increased. At speeds greater than synchronism the armature acted like a condenser. If the armature were rotated the other way, the impedance continually increased as the speed increased. He also proved experimentally that the impedance did not vary at all as the speed altered, if only single-phase alternating-currents were used. Latour gives a complete theoretical discussion of this property, and mentions several practical uses that can be made of his discovery, as, *e.g.*, constructing self-exciting polyphasers, etc., most of which are mentioned in his patent applied for on 13th December, 1900.

A. R.

Rectifier. F. J. Koch, Jun.

(Elektrotechnische Zeitschrift, vol. xxii., 10 October, 1901, pp. 853–854.)

When a rectified current is used to charge a battery, current passes into the battery only so long as the electric motive force of the rectified current is greater than that of the battery, and consequently in each current impulse (corresponding to each half cycle in the alternating current) there is a period during which the battery receives no charge, and two points where the opposing electric motive forces are equal and the current is zero. The Author, in his device, breaks the circuit at one of these points and closes it again at another. This he does by a polarized relay with two opposing shunt windings, one taking the alternate pressure and the other the battery pressure; the relay is arranged so as to close the circuit only when the alternate pressure is of the same sign as and greater than the battery pressure. The self-induction of the relay windings and the armature inertia, however, have the effect of retarding the moments of opening and closing, and the Author, to remedy this, includes in series a condenser and a coil, with adjustable iron core, by which the phase of the current in the relay windings can be regulated so that the circuit is opened at the proper moment. If the battery pressure be nearly equal to the maximum alternate-current pressure, the period between closing and opening the circuit will be far shorter than that between opening and closing, and too short for proper working. On this account the Author inserts a choking coil in the main circuit,

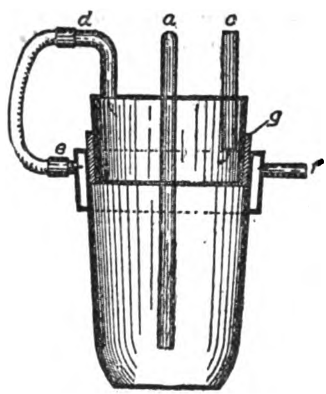
which has the effect of spreading out the current curve, making the time of closed circuit longer. A small apparatus for rectifying 20 amperes at 120 volts and 50 ~ was constructed, and worked quite sparklessly.

G. H. B.

Combustion Apparatus.

(Frank. Inst. Journ., vol. clii., December, 1901, pp. 469–471.)

The Committee on Science and Arts of the Franklin Institute issues a favourable report on the combustion apparatus invented by P. W. Shimer, of Easton, Pa., the object of which is to simplify the determination of carbon by the combustion method. Instead of the separate furnace with oxygen supply, and the usual tubes of platinum, porcelain, or glass, a platinum crucible is used having the upper portion water-jacketed, with a water-cooled copper stopper provided with inlet and outlet tubes. A blast lamp and Bunsen burner supply the necessary heat, and air is employed for the combustion. The woodcut shows the apparatus, the crucible having the form and dimensions of ordinary crucibles used for fusions. The water-cooled chamber is on the outside ½ inch wide and ⅛ inch deep, with short inlet and outlet tubes *e* and *f* placed horizontally on opposite sides. The hollow stopper, made of sheet copper, has a copper tube *a* passing through it for admission of air to the crucible; *c* and *d* are copper tubes for inlet and outlet of the cooling water, *g* is a small rubber band to make a tight joint between the stopper and the crucible, and it is protected by the water-cooled surfaces. The arrows show the direction of flow of the water. The usual absorption tubes and filter tube for air are employed.



F. J. R.

Economy of Clearance in Small Steam-Engines. A. Kingsbury.

(Horseless Age, vol. viii., 11 December, 1901, pp. 796–797.) Paper read at the New York meeting of the American Society of Mechanical Engineers (December, 1901). Slightly condensed.

The Author made an elaborate series of tests to determine the effect of clearance on the economy of a small steam-engine (having cylinder of 5 inches diameter and 7 inches stroke), and found that

there was a regular increase in the water consumption from 52 lbs. to 56 lbs. per I.HP. per hour, as the clearance was increased from 10 per cent. to 34 per cent. The increase of clearance, however, was accompanied by an increase in exhaust pressure, corresponding to less complete expansion, also by decrease in compression; and these facts, together with the increase in clearance, were jointly responsible for the decrease in economy.

E. H. C.-H.

Automobile Boilers. J. W. JONES.

(Horseless Age, vol. viii., 18 December, 1901, pp. 817–819.)

The suitability of various types of boilers for motor vehicles is considered, and also their relative economy. The Author has compiled the following Table from observations made during a recent 500-miles' road trial:—

Type of Boiler.	Heating Surface in Square Feet.	Water Consumption. (Speed 15–18 Miles an Hour.)		Water Consumption per Mile.	Gasoline per Mile.	Steam Pressure per Square Inch.
		Gallons.	Miles.	Gallons.	Gallons.	Lbs.
Victor fire tube . .	50	26	20[1]	1·3	1–6	200
Tol. water tube . .	36	35	30[1]	1·16	„	200
White flash . . .	30	20	26[1]	0·77	„	150 to 250

The weight of all carriages with supplies and equipment was about 1,350 lbs. Each boiler is rated at 6 HP.

C. R. D'E.

Point of Ignition in Gas-Engines. C. E. LUCKE.

(Horseless Age, vol. viii., 4 December, 1901, pp. 769–771.)

An elaborate series of experiments was made with an Otto engine having a cylinder 5½ inches in diameter, with a 12-inch stroke. Sets of cards are reproduced, and the conclusion is arrived at that cards which have a vertical combustion line have not the greatest work area, but, on the contrary, more work is turned out by the engine when the pressures do not rise so suddenly as to give a vertical combustion line. This is inexplicable except on the ground that at high pressures less heat is developed or more

[1] Miles travelled.

gets away suddenly, or that the specific heat of the gases rapidly increases with pressure. The Author's results have been corroborated by a series of tests on a Fairbank Morse engine, reported in the Journal American Society of Mechanical Engineers, December, 1900.

E. H. C.-H.

Ignition. G. Lavergne.

(Locomotion Automobile, vol. viii., 28 November, 1901, pp. 753–754; and 5 December, 1901, pp. 769–770.)

The Cannstat-Daimler firm are now using an alternating-current sparking apparatus having the advantages of the magneto while dispensing with any contact pieces subject to wear. Ignition by incandescence is based on the fact that spongy platinum or platinum wire will maintain incandescence when in contact with carburetted air. This system has no flame, and is not interfered with by wet or wind. Stoppage of the engine, or variation of the point of ignition, is easily determined by a valve controlling the admission of carburetted air on to the platinum. In this way a de Dion motor can be regulated over a range of 1,200 to 3,200 revolutions per minute. The objection to the method has chiefly been the danger of premature explosions, but this danger is absent in the Diesel motor, which only compresses pure air.

E. H. C.-H.

Alcohol Motors. É. Hospitalier.

(Ind. Élect., vol. x., 10 November, 1901, pp. 496–502.)

This Paper contains full details of twenty-seven types of alcohol motors, together with the power and consumption figures on half and on full load. The tests were made with two grades of alcohol, viz., pur edenaturalised alcohol, or "moto-schnick," consisting of 100 parts by volume of ethyl, 10 parts of methyl alcohol, and 0·5 part of heavy benzine, and "electrine" consisting of "moto-schnick" and light benzine in equal proportions. The B.HP. trials were made with a Prony brake. The Author points out the great advances which have been made in these motors during recent years, and that they now give practically the same power, for a given cylinder volume and piston speed, as petrol motors.

C. R. D'E.

Alcohol Motors. L. PERISSÉ.

(Locomotion Automobile, vol viii., 12 December, 1901, pp. 786–787.)

This article gives the results of trials by Ringelmann at the trials organised by the Minister of Agriculture, France:—

(A) With alcohol carburetted with 50 per cent. of benzine. The consumptions per B.HP.-hour were: Fritscher Houdry engine, 1·27 B.HP. at 430 revolutions per minute, 645 grams; Aster engine, 2·3 B.HP. at 1,600 revolutions per minute, 626 grams; Japy engine, 3·75 HP. at 310 revolutions per minute, 409 grams; Otto engine, 6 B.HP. at 240 revolutions per minute, 435 grams; Pruvost engine, 9·6 HP. at 223 revolutions per minute, 379 grams; Merlin engine, 3 HP. at 280 revolutions per minute, 529 grams; Bruhot engine, 16·1 HP. at 176 revolutions per minute, 382 grams. Attention is directed to the comparison of these results with some obtained with an "Economique" engine tested in Switzerland. This engine gave 20·1 B.HP. at 200 revolutions per minute, and consumed 272 grams of 50 per cent. alcohol, 324 grams of 80 per cent. alcohol (20 per cent. benzine), and 356 grams of pure commercial alcohol per B.HP.-hour.

(B) With pure commercial alcohol the consumptions per B.HP.-hour were as follows: Japy engine, 3·75 B.HP. at 308 revolutions per minute, 565 grams; Pruvost engine, 9·6 HP. at 222 revolutions per minute, 507 grams; Duplex engine, 8·2 HP. at 230 revolutions per minute, 710 grams; Gnome engine, 4 HP. at 368 revolutions per minute, 674 grams; Phœnix engine, 6·22 HP. at 490 revolutions per minute, 688 grams; Bardon engine, 2·6 HP. at 800 revolutions per minute, 862 grams; Bruhot engine, 16 B.HP., 491 grams; Economique" engine, 3·04 B.HP. at 253 revolutions per minute, 475 grams. Engines by the same maker of 15 B.HP. and 30 B.HP. consumed respectively 356 grams and 387 grams.

The Author considers that the proportion of methylene added to alcohol in France should be reduced from 10 per cent. to 1 per cent.

C. R. D'E.

Comparative Trials with Petrol and Alcohol. E. DIEUDONNÉ.

(Locomotion Automobile, vol. viii., 28 November, 1901, pp. 759–761.)

This Paper gives the results of experiments by H. Güldner on a single cylinder vertical engine, water-cooled and with electric ignition, cylinder 96 millimetres bore × 100 millimetres stroke, normal speed 1,000 revolutions per minute. The petrol used had a specific gravity of 0·68, and the alcohol was ordinary commercial alcohol of 88 per cent. to 90 per cent. purity. The HP. was taken with a Prony brake. The average of the result gave 4·12 B.HP.

with petrol and 3·89 B.HP. with alcohol. With petrol 351 grams per B.HP.-hour were consumed, and with alcohol 691 grams per B.HP.-hour. This is equivalent to 3,861 calories absorbed with petrol and 3,904 calories with alcohol per B.HP.-hour, and a cost of 0·14 franc with petrol and 0·216 franc with alcohol per B.HP.-hour, at present prices in Germany. A sectional elevation of the engine is given.

C. R. D'E.

Variable Speed-Gear. G. Jougla.

(Locomotion Automobile, vol. ix., 2 January, 1902, pp. 8–10.)

This gear, which is the invention of R. de Montais, is of the expanding belt pulley type. On each pulley shaft are two sliding bosses, with a fixed boss between them. To the sliding bosses are pivoted the inner ends of levers whose outer extremities are pivoted to the plates which form the pulley rim, and which are interlaced by a system of levers. On the fixed central boss are pivoted short arms which are also pivoted to the main pulley arms at the centre of their length. Spiral springs are mounted on the pulley shafts so that they press upon the sliding bosses and tend always to expand the pulleys by forcing together the sliding bosses. By means of a system of levers the sliding bosses of one of the pulleys are under control, and the diameter of this pulley can be varied at will. As one pulley expands, the other contracts, due to the increased belt tension. The belt may be caused to run loose by fixing the diameter of the pulley ordinarily under control and pulling out one loose boss of the other pulley, and so reducing its diameter.

C. R. D'E.

10,000-*Volt Cable in* 1888. O. Schaefer.

(Electrician, vol. xlviii., 22 November, 1901, pp. 178–180.)

A cable with three strands, each of nineteen strands of 1·53 millimetres in diameter, insulated with vulcanized rubber to a radial thickness of 4·25 millimetres on each core, and also a cable with three cores of the same copper, insulated to the same radial depth with a material, mainly composed of hydrocarbons, called Kabelit, were laid underground for 3 miles in part of a 25-mile overhead transmission at 11,000 volts, from Meran to Bozen. They were tested at 20,000 volts, and after two years, in 1890, a fault developed in the rubber cables alone, and that near n exposed end. The Author claims these to be the first stranded

three-phase 10,000-volt cables ever made. The capacity per mile reaches the high figure of 0·78 microfarad per mile for rubber and 0·568 microfarad for Kabelit.

M. O'G.

Large Alternators. A. ROTHERT.

(Écl. Électr, vol. xxix., 30 November, 1901, pp. 307–328; and 7 December, 1901, pp. 362–374.)

The Author gives a table containing full constructional details of twenty-three different types of large alternators, most of which were exhibited at Paris in 1900, and then briefly comments on the characteristic features of the various machines. The peripheral velocity varies from 14 metres to 38·5 metres per second. Of the twenty-three machines referred to, six had hole windings, eleven slot windings with the slots nearly but not quite closed at the top, and the remainder had entirely open slots. The number of slots per pole in the case of three-phasers varies from three to fifteen, the number most commonly employed being six; with only three slots per pole there is a very prominent third harmonic in the electromotive force wave. The armature coils in almost every case have a width equal to the pole pitch. The air-gap varies from 6 millimetres to 8 millimetres. The pole-pieces are in some cases solid, in others laminated; in the Author's opinion, they may be solid if, with at least six slots per pole (in the case of three-phasers), the width of the slot at the top does not exceed half the length of air-gap. The length of the pole-piece parallel to the armature circumference is in most cases two-thirds of the pitch. The current-density in the field coils mostly exceeds 3 amperes per square millimetre (about 2,000 amperes per square inch), and in the armature coils falls below this value. The induction in the armature core-discs is in most cases 4,000 to 5,000 (for 50-cycle machines). The leakage coefficient of the field magnet varies from 1·18 to as high a value as 1·74; the Author draws attention to the importance of calculating this coefficient. The ratio of armature to field ampere-turns seldom exceeds 0·3 (it varies between 0·15 and 0·47). The copper loss in the armature varies from 0·7 per cent. to 2·5 per cent., and the iron loss from 2·25 per cent. to 5·5 per cent., in most cases exceeding 4 per cent. The copper loss in the field varies from 0·36 per cent. to 2·6 per cent. The dimensions of different machines of the same output, and running at the same speed, vary considerably, and the Author considers that there is plenty of scope for reducing the dimensions below their present-day values.

A. H.

Alternators with Dampers. J. Fischer-Hinnen.

(Electrical World and Engineer, vol. xxxviii., 28 December, 1901, pp. 1058–1062.)

The form of damper (amortisseur), originally described by Leblanc, consisted of a kind of copper ring on each magnetic pole of the alternator. Its effect was to reduce the drop of pressure by choking back part of the armature reaction. It was no real help for the parallel running of single-phase machines, as outside energy was required for synchronizing the rotor. For polyphase machines, however, it was useful, as when they were running in synchronism no effect was produced on the damper, which acts only when the rotor gets out of synchronism. The Author considers that the action of the damper is identical with that of the secondary winding of an asynchronous motor. He first of all developes the theory of polyphase motors, and then applies his formula to show the action of the dampers in polyphase generators. He investigates the problem of the influence of the damper on the working of a flywheel machine which has a variable speed on account of the unfavourable position of the crank. Under these circumstances he shows that the damper has some slight influence on the uniform running of the machine. Its main use is to insure greater stability for paralleling. He considers that in many cases single-cylinder engines are preferable to compound engines. He points out that the change from maximum to minimum speed is steadier for a single-cylinder engine than for a compound engine, although, of course, the energy variations during each stroke are greater for the single-cylinder engine. The compound engine is much more likely to produce high harmonics in the electromotive force wave. If a machine is only run for an hour or two at full load, and on a light load for the remainder of the day, then a good single-cylinder machine is the more economical in steam consumption. Some large generators, quite capable of supplying the night load, are yet not able to furnish the magnetizing current for the transformers in the daytime, owing to the great pressure drop. For single-phase generators dampers are of very little use. They only reduce the pressure drop by about 30 per cent. Figures from actual machines are quoted to show that the weight of copper in the damper is about half that on the field. He says that the same purpose could have been attained at one-fifth the cost by strengthening the magnetic field.

A. R

Variations in the Exciting Current of an Inductor Alternator.

W. DUDDELL and E. W. MARCHANT.

(Electrician, vol. xlviii., November 29, 1901, pp. 224–225; and 13 December, 1901, pp. 302–304.)

Measurements were made of the wave form of the exciting current of an inductor alternator by the Joubert contact method, and the Authors give clear theoretical explanations of the results of their experiments. They prove (1) that the variations of the exciting current may be considerable in certain cases. (2) The exciting current is made up of a direct and an alternating current component, the frequency of the latter being double that of the armature electromotive force. (3) The added alternating current is asymmetrical. (4) The amplitude of this current depends very little on the resistance of the field circuit. (5) The maximum values of the exciting current on open circuit occur approximately when the armature electromotive force has its maximum or minimum values. (6) In this case also the amplitude of the exciting current is nearly proportional to the amplitude of the armature electromotive force wave, the speed being kept constant, and (7) it is practically independent of the speed for constant mean exciting current. (8) The superimposed alternating current in the field is reduced when the machine is loaded, and becomes very small when the machine is short-circuited. (9) These variations in the exciting circuit tend to reduce the efficiency of the machine owing to hysteresis and eddy current losses. (10) The electromotive force in the field coil may prove dangerous to insulation, etc., owing to resonance effects. The Authors point out how this effect can be completely eliminated by properly designing the machine. A. R.

Study of Polyphase Machines by the Oscillograph. A. BLONDEL.

(Écl. Électr. vol. xxix., 14 December, 1901, pp. 391–400.)

Complete data are given of experiments on a two-phase and a three-phase machine, which were driven by a direct-current motor connected to a battery of accumulators so as to insure constant speed. The characteristic curves are given of the machines on open circuit, on inductive and non-inductive loads, and on short circuit. Experiments were also made to find out how the voltages in the various phases altered when one was loaded and the others left on open circuit. The results agree very closely with those arrived at by the ordinary theory. When, however, the instantaneous values of the exciting current, the volts and the armature currents, were oscillographed, very curious effects were observed. On open circuit the three-phaser gave a

very approximate sine curve, and the exciting current was practically a straight line. When one phase was loaded the exciting current pulsated with a frequency twice that of the alternating current. When the three phases were loaded symmetrically the frequency was six times that of the armature current, but the amplitude of the disturbance was much smaller. Similarly in the two-phase machine the frequency of the pulsation of the exciting current was four times that of the armature current.

A non-inductive load on one of the phases lowers the electromotive forces in the others. If the load be a capacity load, then the other electromotive forces may be slightly raised. The shapes of the P.D. waves on unequal loads are, of course, quite different. In the three-phaser the shape of the P.D. wave across the loaded phase is approximately sinoidal, that across another is a peaky wave, and across the third is a flattened wave. In the two-phaser the effects of the armature slots on the shape of the P.D. wave are very pronounced, making it rippled. When one phase is loaded enormous distortions from the sine shape are produced. One P.D. wave becomes peaky and the other flattened. When one phase is short-circuited the P.D. wave in the other phase loses its symmetry, and the pulsations of the exciting current are very large. It is curious that these effects do not alter very appreciably the characteristics of the machines.

A. R.

Niagara-Falls Power Transmission Plant. L. B. STILLWELL.

(Amer. Inst. Elect. Engin., Trans., vol. xviii., August–September, 1901, pp. 541–627.)

The Paper contains an illustrated historical account of the development of the Niagara Falls Power Transmission System, with a critical discussion of the original plant and of the various modifications which have been introduced. The Author adduces the history as a "demonstration of the ability of applied electrical engineering science to attain in commercial practice results predicated in large degree upon theory." The load curve for local service for the twenty-four hours ending at midnight on the 20th July, 1901, affords an interesting example of the high load factor that may be obtained from a large plant which supplies most of its power to factories in which the processes employed are continuous, the minimum local load during this period being 14,200 kilowatts, and the maximum 15,700 kilowatts. The Author states that during the two years ending with June, 1901, the cost of maintenance and repairs has been less than 1 per cent. in the case of the generating plant, including alternators, exciters and switch gear; and about 2 per cent. for the motive power plant, including turbines, governors, pen-stocks, shafts, inlet racks, etc.

G. W. DE T.

Versailles Electric Railway. F. Drouin.

(Génie Civil, 26 October, 1901, pp. 413–419.)

The line from the Invalides, Paris, to Versailles, which has been equipped electrically, is supplied from the station at Moulineaux. The system of supply is three-phase current at 5,000 volts, which is converted by rotaries to continuous current at 500 volts. Of the six cables leaving the station, two go to Meudon and Viroflay, and four to a distributing box at the Pont de Passy, from which two go to the Invalides, two to the Champ-de-Mars, and one to Courcelles. The cables are constructed on the Berthoud-Borel system, in which the wire of the outer strands of each core is separately insulated; each core is paper-insulated, and the three are made up with jute worming, and the whole insulated with paper, covered with two layers of lead, and then with an armouring of two steel ribbons. The sections of each core vary from 100 square millimetres to 150 square millimetres. The cables are laid at a depth of half a metre in the ballast close to the track. There are three main sub-stations, at the Champ-de-Mars, Meudon, and Viroflay. Each contains four Thomson-Houston rotary converters of 300 kilowatts normal and 450 kilowatts maximum capacity. The pressure is regulated on the alternate-current side, by a regulating transformer with movable armature. Each rotary is supplied by a group of three transformers in triangle, reducing the pressure to 340 volts. They are ventilated by a fan driven by an induction motor. The rotaries are started by continuous current supplied from a 40 kilowatts generator driven by an induction motor. There are also sub-stations for lighting and pumping at each station on the line. The line is supplied by a third rail of the same section as the track rails, and weighing 46 kilos per metre. They are supported on projecting sleepers by chairs fixed to insulators of paraffined wood, and are divided into sections of one kilometre. In laying the track an erecting car drawn by a steam locomotive was employed. This contained a 45-HP. engine and dynamo, supplied with steam from the locomotive; the current was used for lighting and for electric drills carried on trolleys.

The electric locomotives, ten in number, are capable of drawing a load of 200 tons at a speed of 50 kilometres per hour up an incline of 1 per cent. Their length is 13 metres and weight complete 50 tons. Four have geared Thomson-Houston motors, and six have direct-coupled motors by Brown-Boveri and Westinghouse. The geared motors have four poles, the direct-coupled six. The ratio of reduction is 1 : 3. There are four motors on each locomotive, two on each bogie. The motors are all mounted rigidly on the truck, with a spring coupling to the axle. The armature or the gear is mounted on a hollow shaft encircling the axle; the coupling consists of six spiral springs connecting the

spokes of the car wheel with a star on the end of the hollow shaft. The Westinghouse brakes are supplied by a Christiansen compresser, driven by a motor with automatic switch. A certain number of motor cars and trains on the multiple unit system are in use.

G. H. B.

Modern Electric Railway Practice. A. H. ARMSTRONG.

(Amer. Inst. Elect. Engin., Trans., vol. xviii., August–September, 1901, pp. 629–641.)

Mountain railways, and high-speed passenger or freight trains which run long distances without stopping, offer, in the Author's opinion, a field for the use of induction motors. In all other cases he prefers to employ continuous-current 500-volt motors, supplied through converter sub-stations from an alternating system. Where a growing neighbourhood has to draw its supply of power for electric tram-cars from a continuous-current supply station, he advises the use of rotary converters fed from the station bus-bars, and supplying alternating current to the sub-stations through step-up and step-down transformers. These converters may be transferred to sub-stations when the growth has reached the point which warrants the installation of alternate-current generators. On elevated or underground railways with heavy trains and frequent stoppages, the motors must be capable of efficient acceleration with very high torque, and must not overheat to an unsafe degree from repeated temporary overloading, while the controlling apparatus must provide for their efficient handling during fractional speed running. These requirements all point to the use of continuous-current motors. They can give a torque much in excess of any service demand without sacrificing their running qualities at light loads, while induction motors can meet these infrequent overload demands only by the sacrifice of some of their advantages for normal operation. Comparing the average acceleration efficiencies for the frequency of stoppages usual on American elevated railways, the Author estimates them at over 70 per cent. for continuous-current series motors, with the ordinary series parallel controller, and from 40 per cent. to 45 per cent. with induction motors. In the former case the acceleration efficiency may be slightly increased by the use of a series parallel controller provided for starting with four motors in series, changing first to two in series, and then to all in multiple; he does not, however, consider that the gain of 1 per cent. or 2 per cent. in efficiency warrants the increased complication. In the case of an infrequent service of trains, the elimination of attendance at the sub-stations, when induction motors are used, is an important point in their favour, but, when there is a frequent service, the sub-stations can be served by officials whose presence is required

for other purposes. He suggests that track lines with heavy freight trains or high-speed passenger trains, as well as a local passenger traffic, might with advantage equip their tracks with both high-pressure overhead trolley for the operation of heavy through trains and freight work, and also use a third-rail construction to operate continuous-current 600-volt motors for the local work. He observes that both these systems could be fed from the same generator and transmission lines, operating 25-cycle rotary converters to feed the third-rail system at intervals, and step-down transformers to reduce the pressure to the 3,000 volts or more, required for the overhead high-pressure trolley line.

G. W. DE T.

Trolley Lines without Rails. M. SCHIEMANN.

(Elektrotechn. Zeitschr., vol. xxii., 21 November, 1901, pp. 964–967.)

As against £4,000 to £5,000 per kilometre of trolley lines on rails, including the power station, a railless trolley line costs only £1,000 to £1,250 per kilometre, exclusive of the power station. In July, 1901, a railless service with double overhead trolley line, equipped by Siemens and Halske, was started between Königstun and Königsbrunn in the Bielathal. The 24-passenger cars resemble ordinary omnibuses, and run at 12 kilometres per hour. Goods vans are run at 10 kilometres per hour. The overhead equipment is similar to ordinary trolley lines, but simpler, no frogs or crossings being provided. When two cars meet, one lifts its trolleys off. The trolleys are on the Dickinson principle, but have special lubricated contact shoes instead of wheels, which would not allow of sufficient side motion. The cars are driven through 8 : 1 spur gearings by a motor on each back wheel. Series-parallel control is used, with short-circuited electric brake. The fore-carriage turns on rollers to facilitate steering. The route has a continuous grade of 2½ per cent., and is full of curves, but the road surface is very good. The traction coefficient of the cars on the level road is 25 kilograms to 30 kilograms per ton, *i.e.*, about double the figure for cars on rails. A railless line is essentially for light traffic, and this extra cost of operation is more than balanced by the saving in capital cost over a tramway on rails. A considerable advantage is that each factory can run out wires, and thus have goods delivered cheaply at its doors without transhipment. The results are more favourable than had been anticipated.

E. H. C.-H.

Rapid Transit in London. F. J. Sprague.

(Engineering Magazine, vol. xxii., October, 1901, pp. 1-23.)

The Author considers that rapid transit in London and its suburbs demands the widespread and radical application of electricity, with the construction of new tunnels built, according to a definite system, under the control of a single central authority, and forming a network following main arteries of traffic and connecting busy centres with each other and with outlying districts and suburban stations. The whole system should not only be constructed but worked under a single management. Classes should be abolished, one regular rate of fare established, with workmen's fares within limited hours, and there should be free exchange except on limited routes. Locomotive practice should be abolished, and trains operated in small units which could be combined at will. Electric tramways should replace many of the omnibus lines on crowded streets, and radiate from every terminus of tubular railways, and from most of the suburban stations. Every steam railway should equip at least its suburban service with electricity on a plan which permits of variable train lengths, plural control, high schedule speeds, and the maximum use of the existing permanent way. Maps are given showing existing railways and suggested additions needed to complete a harmonious comprehensive plan.

G. W. de T.

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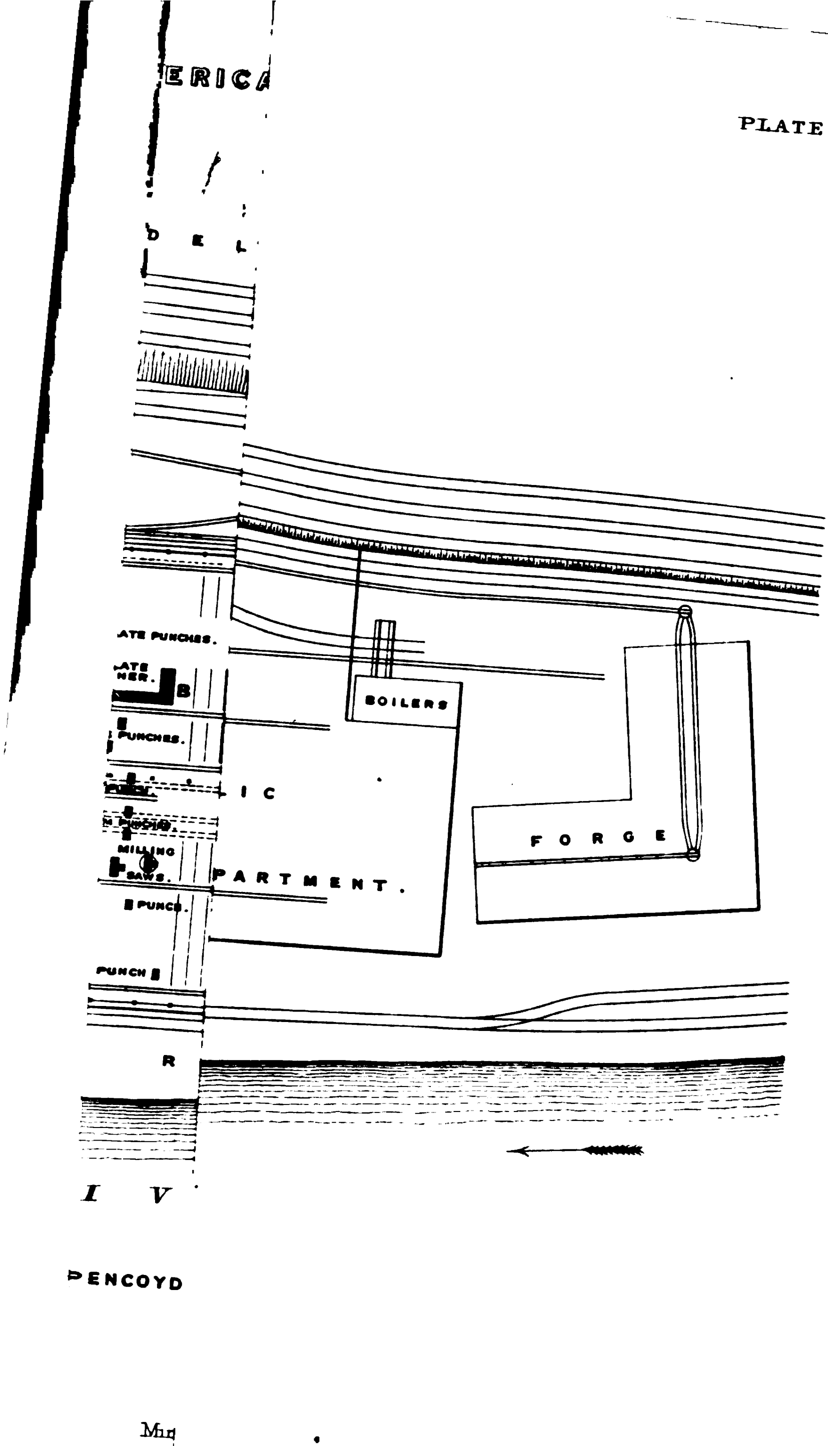

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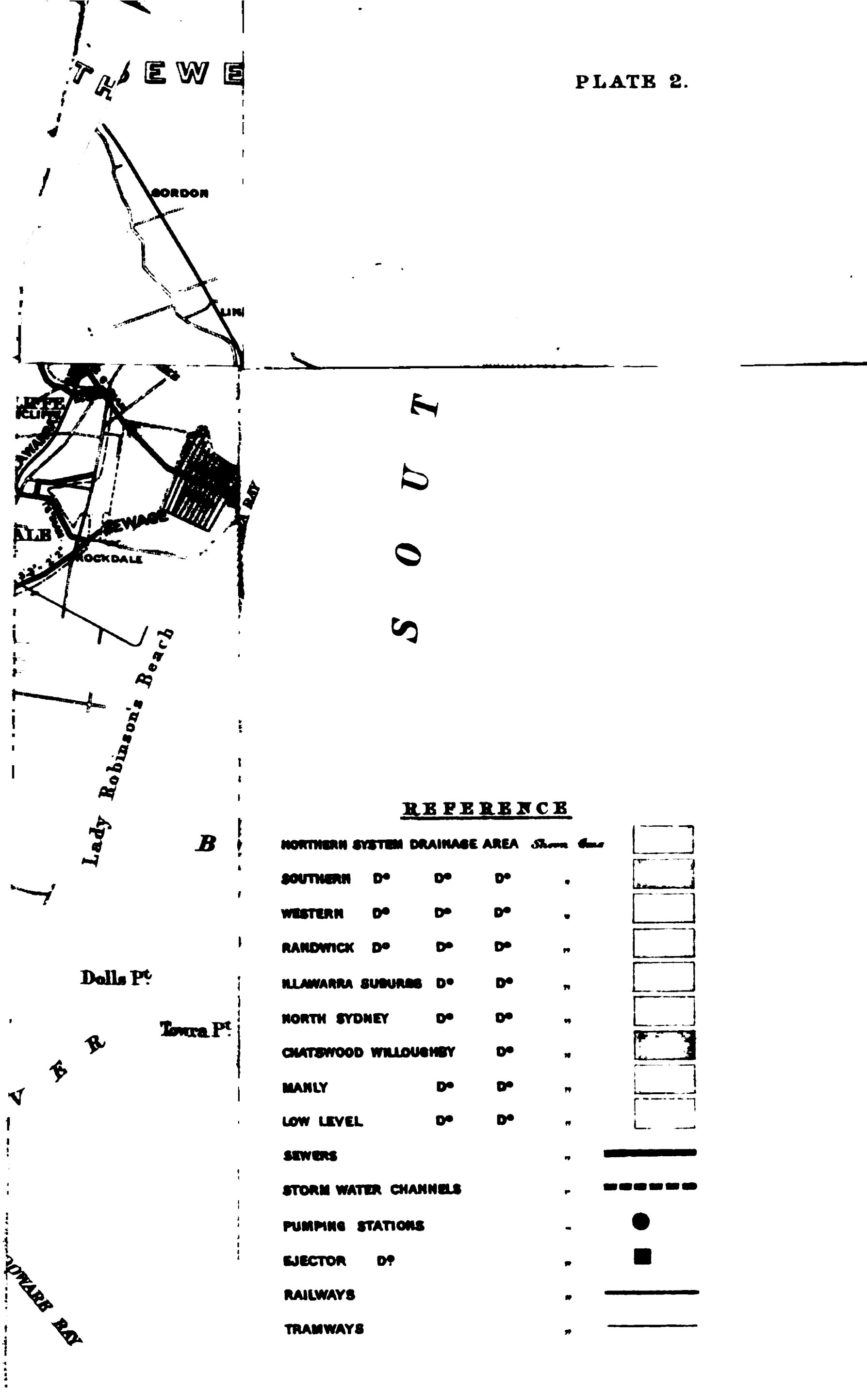

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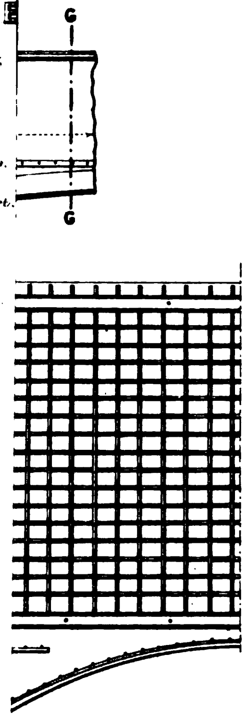

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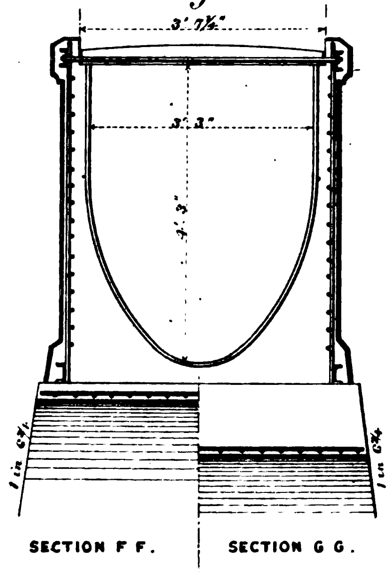

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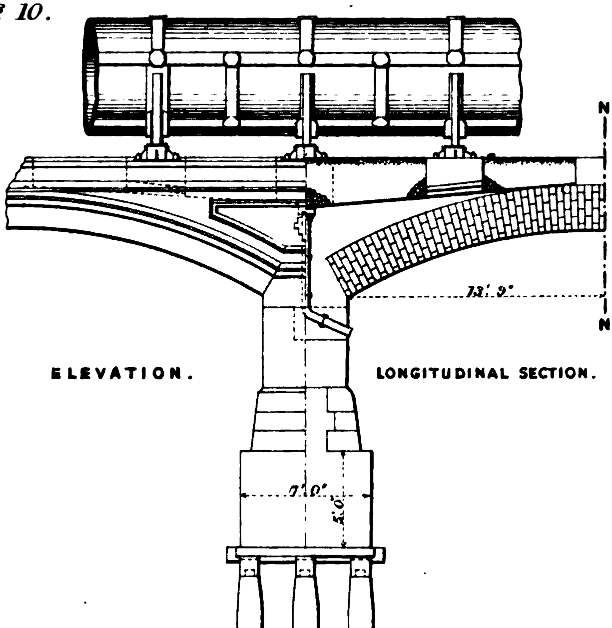

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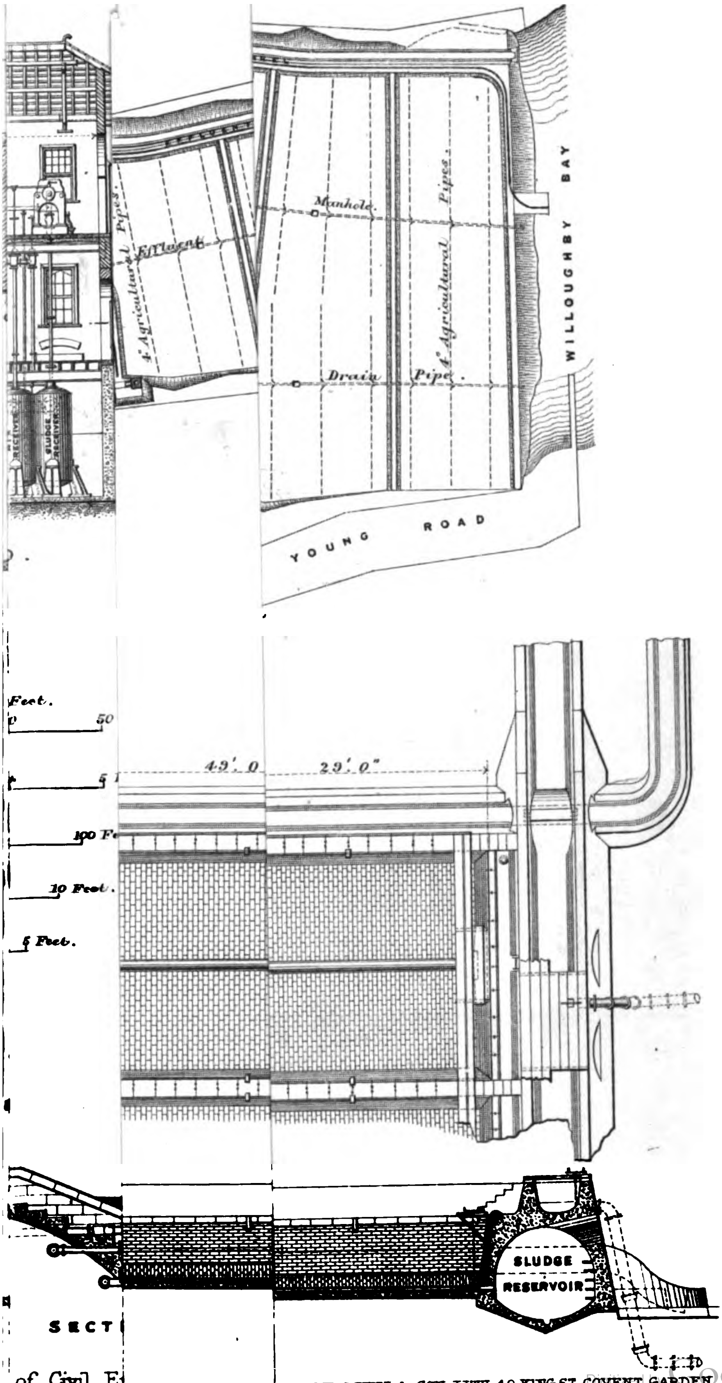

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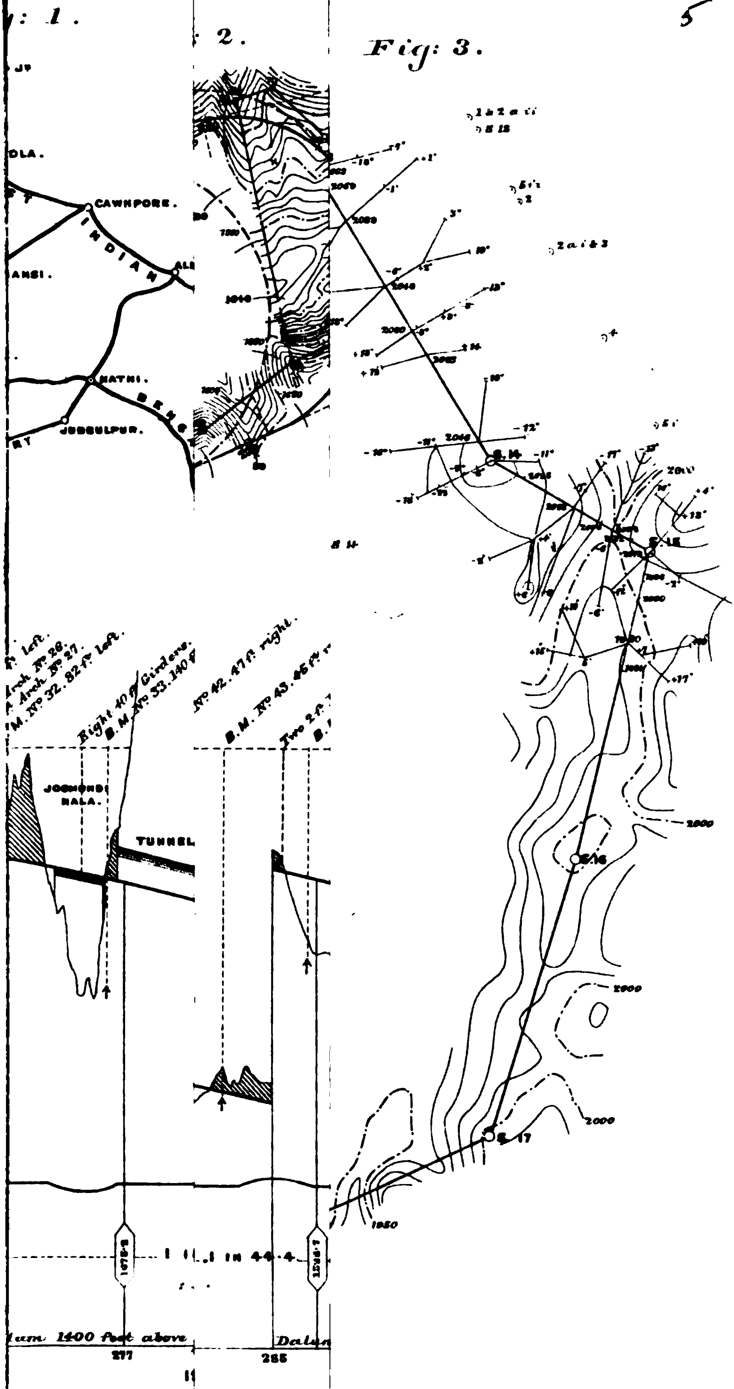

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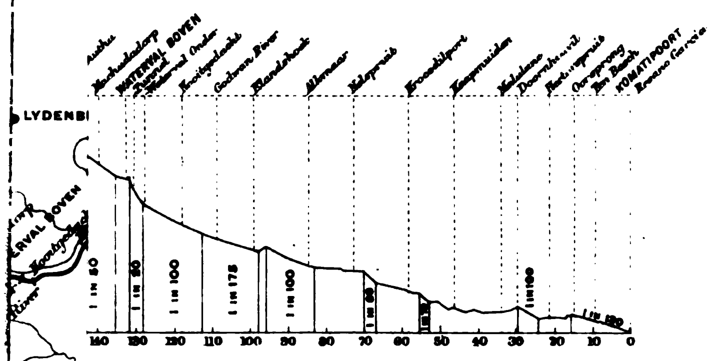

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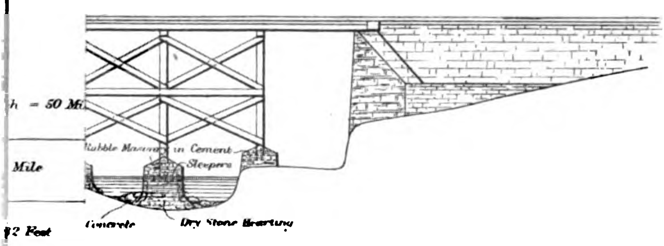

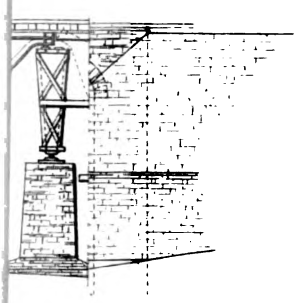

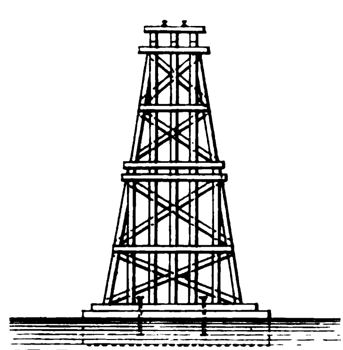

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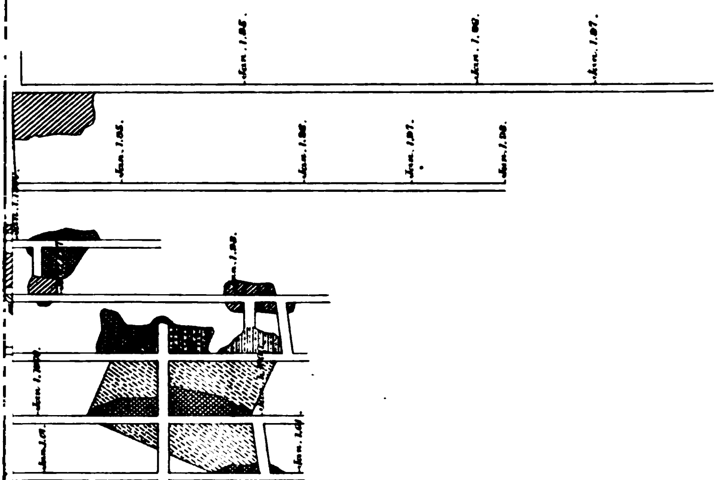

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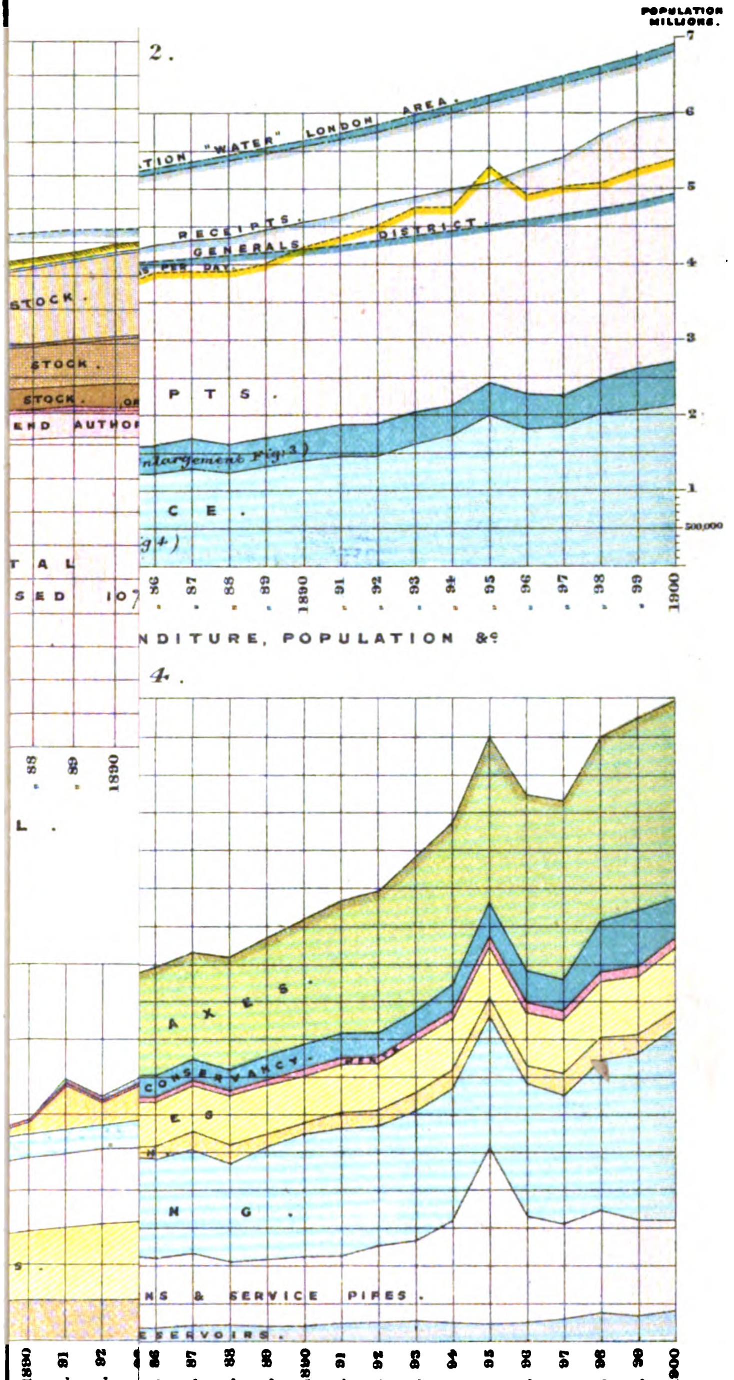

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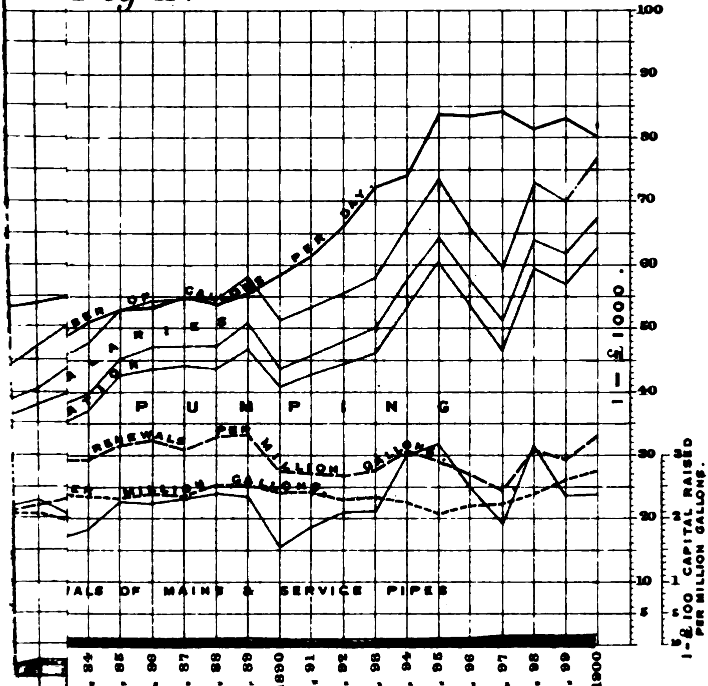

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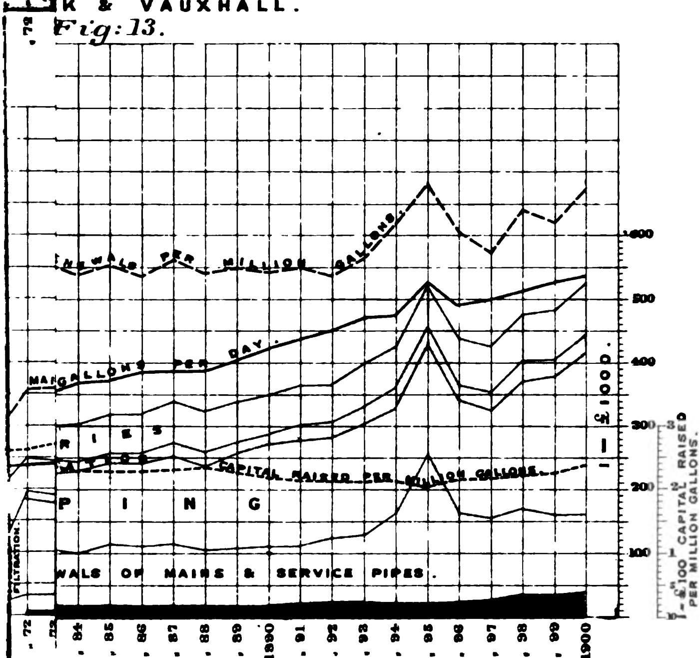

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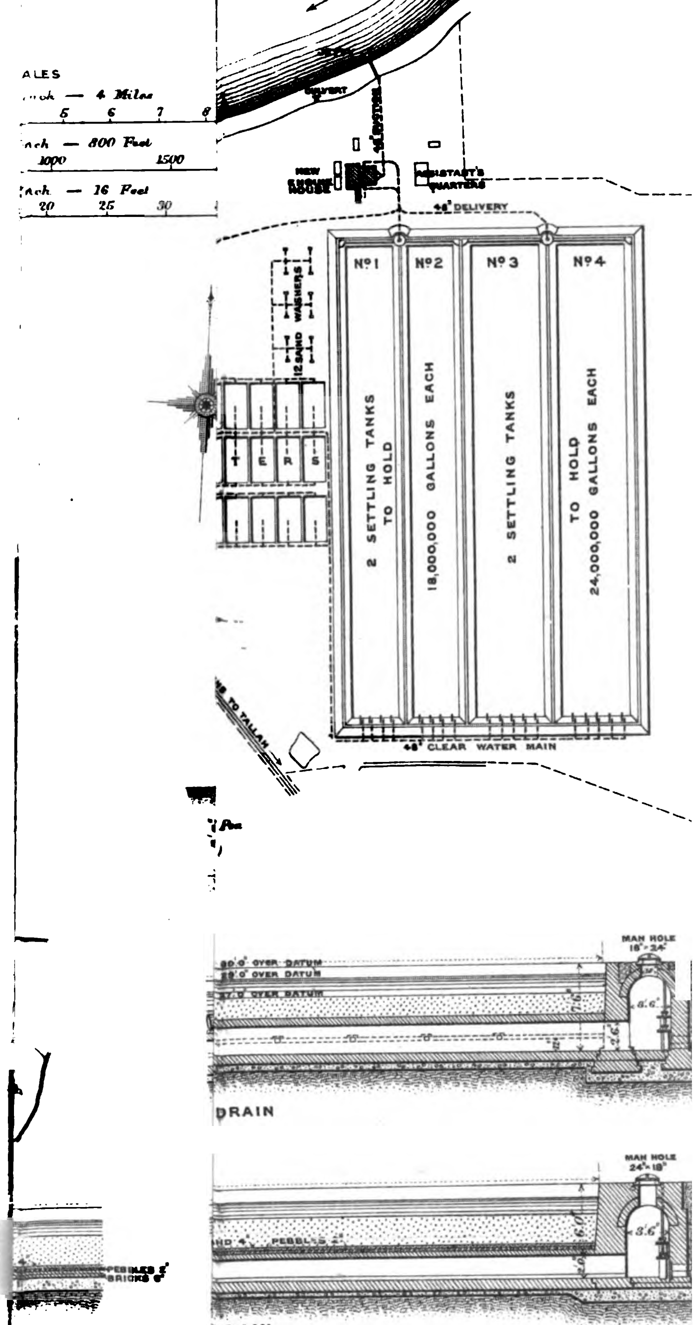

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